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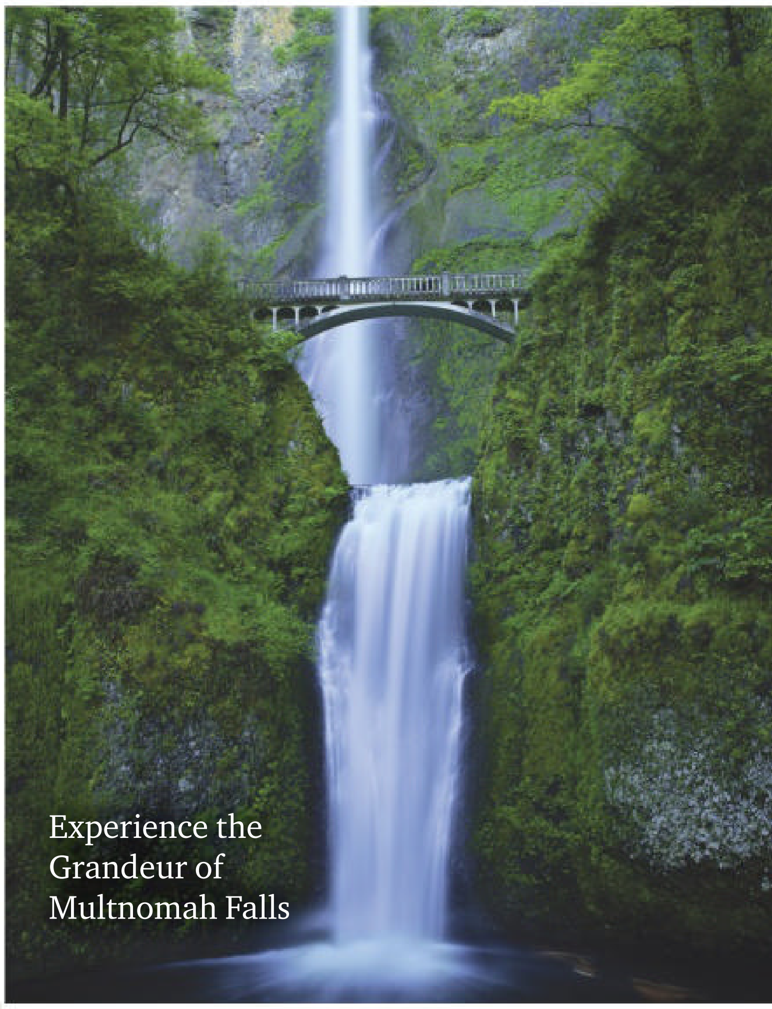

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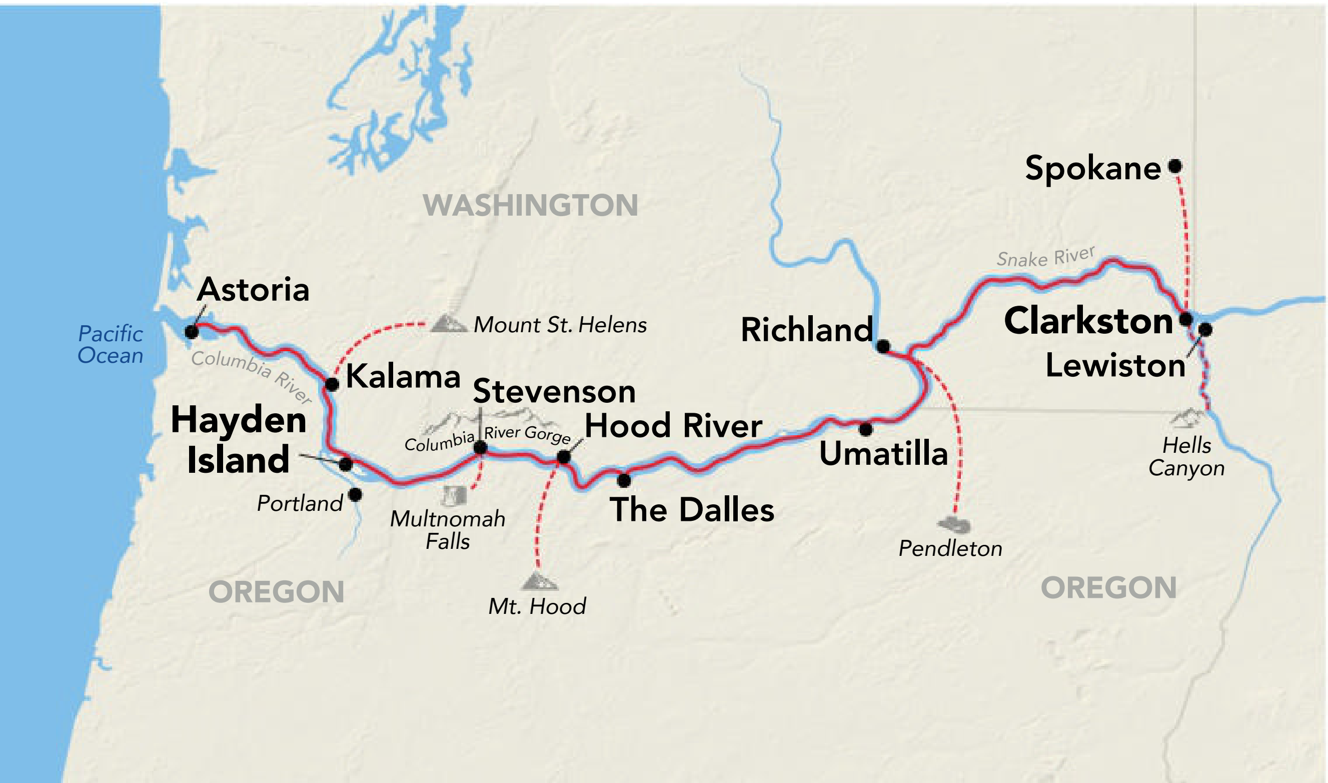
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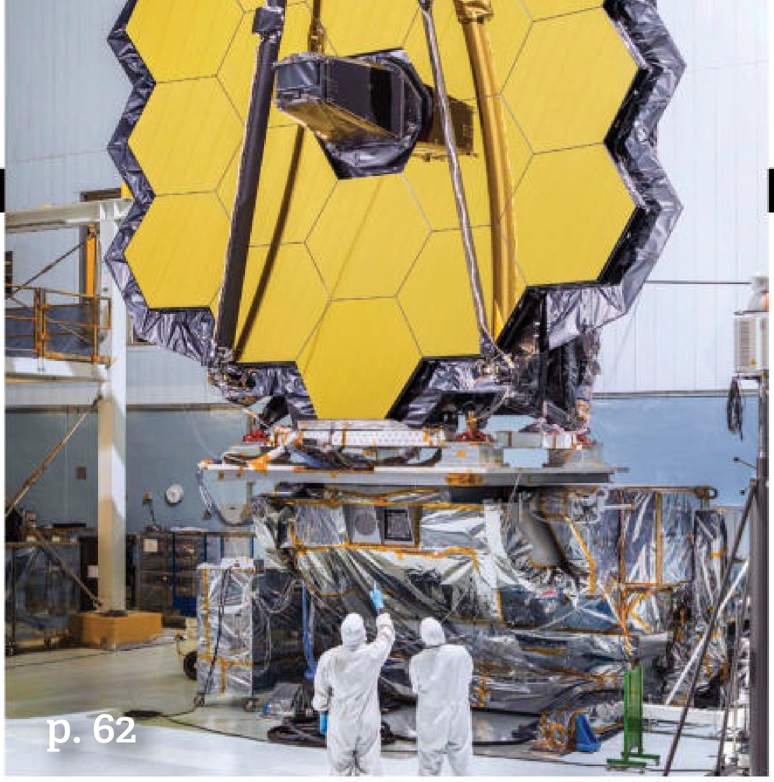
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BY STEPHEN C. GEORGE

Well 'Versed

AS A KID, I learned a surprising amount of science from reading comic books — and I'm willing to bet that some of you did, too. I was particularly attentive to the publications of DC Comics, home of Superman, Batman, the Flash and a multitude of others. At DC, editors often peppered those old four-color stories with interesting scientific information, while certain writers built entire storylines around some arresting new fact or theory. Sure, they stretched concepts a little far in the name of fiction, but the ideas intrigued me enough to spark an abiding interest in science, and a desire to learn the hard facts hinted at in my favorite comic books.

Thus it was that I was introduced to the idea of the multiverse. Long before Hollywood leveraged the concept in popular films, even before the original *Star Trek* TV series devoted an episode to it, comics fans like me were well versed in the study of parallel worlds. For years, the Flash and the rest of the Justice League regularly visited other Earths, each one "almost a duplicate of our own — which coexists with our world in different vibratory dimensions," as one story succinctly put it.

On these other worlds, the heroes frequently met alternate versions of themselves — some older, some younger, some evil. I loved the idea that there could be other versions of me (and my family) out there. Apart from anything else, I figured that there had to be worlds where my annoying older brother was my *younger* brother — or perhaps never even existed at all! It was an interesting concept, you know? Really made you think.

Of course, I no longer wish for my big brother to be lost in the multiverse, but I'm still captivated by what some scientists call "the most controversial idea in physics." It's our cover story this issue and you can read much more about it in "Mapping the Multiverse," on page 34. As you'll see, we also give a nod to other ways that multiverse theory has bled into popular entertainment here on our version of Earth. Enjoy!

When you were growing up, what first sparked your interest in science? Email me at editorial@discovermagazine.com and let me know.

Stephen C. George, Editorial Director

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SUBSCRIPTIONS
Print + digital in the U.S., $37.95 for one year; in Canada, $44.95 for one year (U.S. funds only); includes GST, BN12271 3209 RT; other foreign countries, $51.95 for one year (U.S. funds only).

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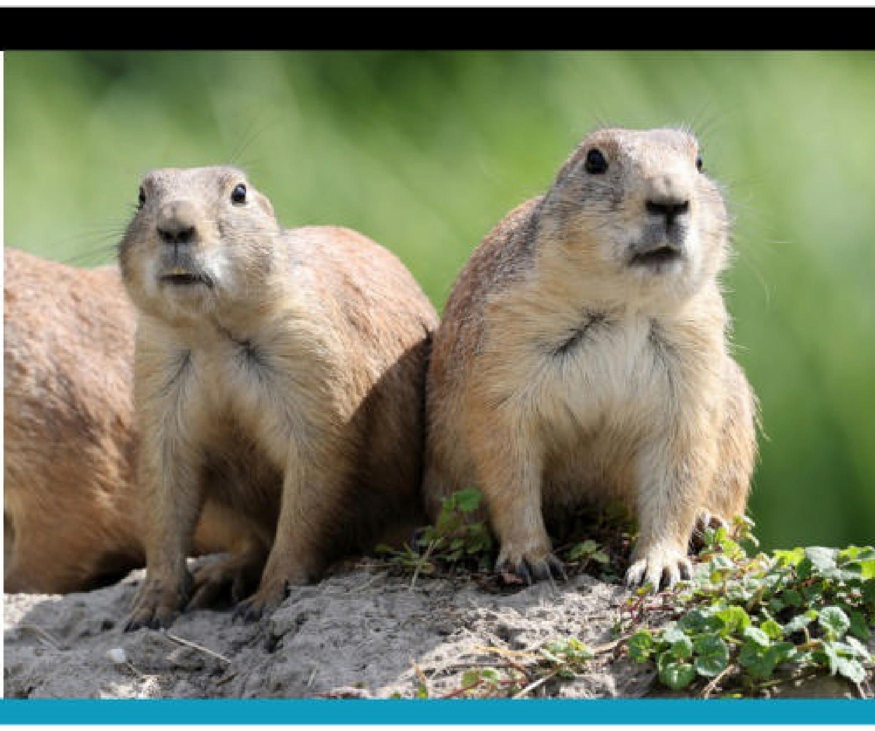
LISTENING EARS

("Shh! Eavesdropping Animals May Be Listening," Sep/Oct 2022)

I got a chuckle out of the article on eavesdropping animals. Our property abuts a large open space which has a number of prairie dog burrows. As most know, they "bark," and there is a very distinct emergency/warning bark they make when danger — often coyotes — approaches. Our black lab is smart enough to distinguish between a regular bark and a warning bark: When he hears the latter, he jumps up and bolts out the door, barking all the way because he knows there is a coyote out there that the prairie dogs are announcing.

Todd Jamison



SOMETHING FISHY

("Invasive Eats," Sep/Oct 2022)

I was surprised that Asian carp was not mentioned in this article. This is probably the biggest invasive problem in the Mississippi watershed; the effort to keep them out of the upper Mississippi and the Great Lakes is immense.

Warren Nilsson

MARISA SLOAN, AUTHOR AND ASSISTANT EDITOR, RESPONDS: *Thanks for your interest, Warren. It's true that bighead carp along with grass carp, silver carp and black carp (collectively referred to as Asian carp) are all invasive in the Mississippi River Basin. The short answer is that we had limited space and wanted to include a mix of freshwater, saltwater, and land species — as well as a mix of species found in various regions of the U.S. This meant leaving a lot of great options on the cutting-room floor.*

But here's a longer answer: While the Monterey Bay Aquarium's Seafood Watch program rates lionfish as a "best choice" for consumer consumption because it is well-managed and caught in ways that cause little harm to habitats/other wildlife, the carp species above are not listed as such. This is because all gear that targets these fish have the potential to harm endangered or threatened sturgeons.

NO AXIS

("Waves of Discovery," Jul/Aug 2022)

The Jul/Aug Out There column contained a fascinating graphic titled "Masses in the Stellar Graveyard." It appears to show observed stellar mass on the vertical axis against an undefined horizontal axis. Please explain the horizontal axis and the near-perfect symmetry.

Charles Gene Hilborn

FROM THE EDITORS: *Charles was the first of many readers to ask what the "missing" x-axis label should be. But there is, in fact, no x-axis to label — "Masses in the Stellar Graveyard" is a graphic, rather than a graph. This also explains the near-perfect symmetry that Charles mentioned; the LIGO researchers who composed the illustration created it to look visually appealing, as well as informative.*

Northwestern University's website even has an interactive version of the graphic that allows you to change the view and re-sort the data into different displays — none of which require an x-axis. Check it out here: https://media.ligo.northwestern.edu/gallery/mass-plot.

ERRATUM

The Sep/Oct 2022 article "Invasive Eats," says, "Not all non-native species are invasive. In fact, corn and wheat, two of the highest yield crops in the U.S., came from overseas, just like many of these invasives." The word *overseas* is an error; we intended to highlight species that readers might be surprised to learn originate from outside the U.S., but the appropriate word should have been *abroad* rather than *overseas*. Corn was domesticated in southern Mexico by Native peoples approximately 10,000 years ago.

WHAT'S FOR DINNER?

In the Sep/Oct issue, which featured our story on "Invasive Eats," Editorial Director Steve George asked: "What's the most unusual thing you've ever eaten?" Below is a sampler platter of our readers' responses. (Disclaimer: *Discover* doesn't endorse any of the dishes mentioned. Some may be dangerous to eat, or their harvest may have environmental or cultural implications. Dine considerately, and at your own risk!)

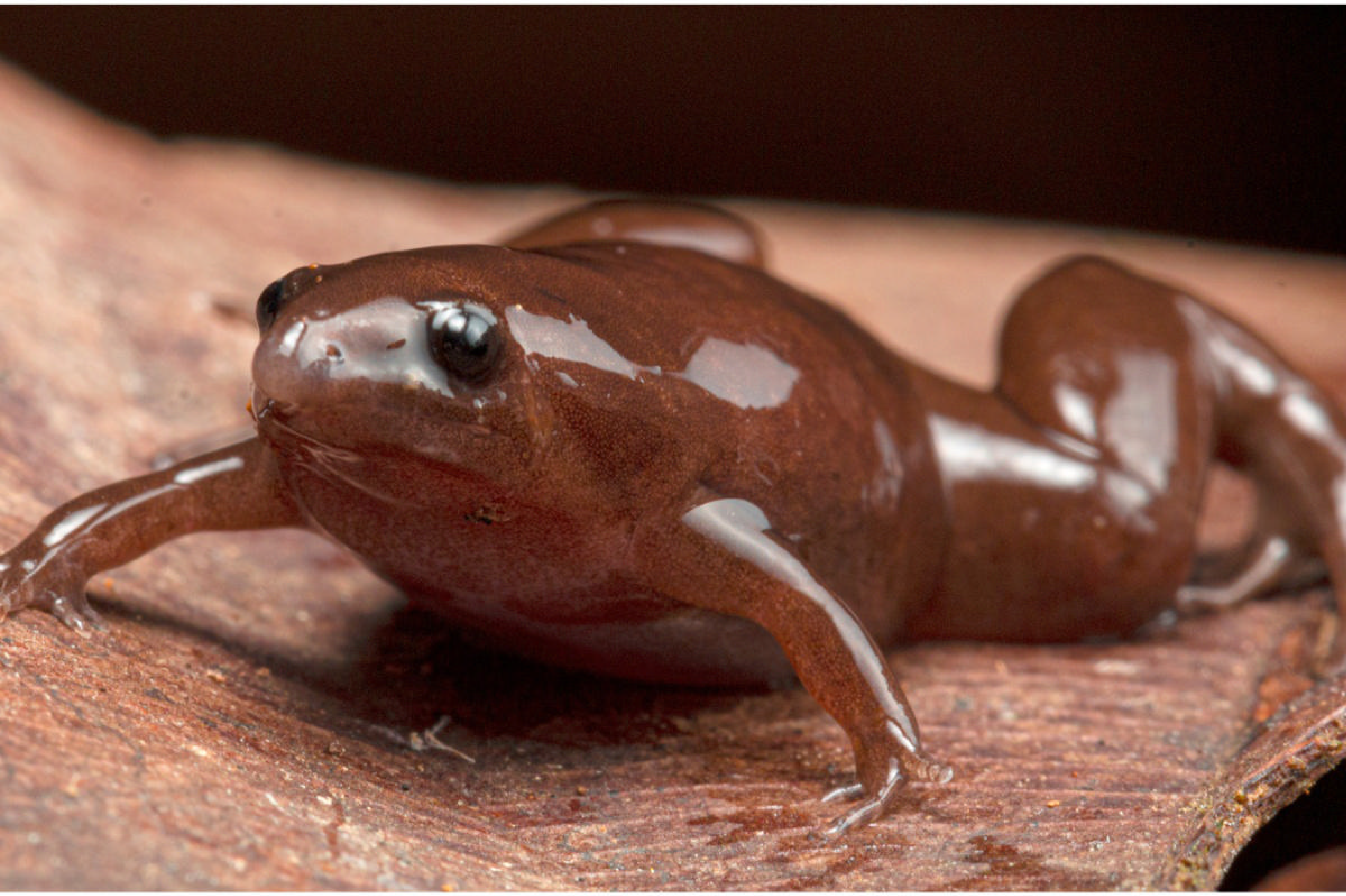
- In the '60s, I was on a business trip in Caracas, Venezuela. I went to a restaurant with acquaintances, and they convinced me to try the **angulas** [baby eels]. The taste was great — but I still recall those hundreds of eyes staring at me while I ate them. —*Pete Schermerhorn*
- While in Vietnam, our guide led us to a very local place which specialized in traditional food. We ate **porcupine** and quaffed **snake wine**; I kind of expected the porcupine to be on skewers, but it was plated professionally and tasted like a rubber band ball ... in a nice sauce. —*Paul Ross*
- On a winter trip to South Korea, I had **roasted silkworms** from a street vendor in Seoul. They looked, smelled, and tasted remarkably similar to the roasted chestnuts I would buy from street vendors in Vienna, Austria, during the winter I lived there. —*Richard J. Moak*

FROM TOP: EDWIN BUTTER/SHUTTERSTOCK; ELIZABETH M. WEBER/DISCOVER

HOT SCIENCE

THE LATEST NEWS AND NOTES

HOW ASTRONAUTS TRAIN • THE SCIENCE OF CLEFT LIP AND PALATE • IF USAIN BOLT RACED A DINO • NOBEL-WINNING CHEMIST • BOOKS LACED WITH ARSENIC



NATURE'S NOSIEST FROG

A shimmering brown body, a spectacular snout and a striking similarity to the tapir would make most animals stand out. But despite all that, the trick to finding the tiny tapir frog isn't to search it out by sight, but by sound. Following the high-pitched, beeping song of these amphibians to specific spots underneath the peatlands of Peru's Putumayo Basin, a team of international biologists and their local guides dug up several of the burrowing frogs in November 2019. The resulting analysis of the specimens — which assessed their genetics, anatomy and auditory behavior in a 2022 paper in *Evolutionary Systematics* — solidified their identity as a new species. According to the team, the presence of these frogs beneath the peat signifies the health of the Putumayo Basin and stresses the need to protect this ecosystem, which remains one of the most biodiverse places on the planet. —SAM WALTERS; IMAGE BY GERMÁN CHÁVE

ARE YOU ASTRONAUT MATERIAL?

RATHER THAN SUPER-GENIUSES OR SUPER-ATHLETES, NASA'S LOOKING FOR SUPER-ROOMMATES WHO ALSO HAPPEN TO BE GOOD SCIENTISTS.

ASTRONAUTS HAVE one of the most competitive jobs in the world — 18,300 people applied to be part of NASA's 2017 class of astronauts, and only 12 made the final cut. But the process of finding astronauts with "the right stuff" has changed over time, and a lot of us earthlings have the wrong idea about what NASA is looking for.

"I think a lot of the public conception is that we choose super-geniuses or super-jocks or super-pilots," says Mike Barratt, a NASA astronaut and physician. "I would say that the astronaut office right now is full of people who are comfortable to be with. I mean, don't get me wrong — we've got a couple of super-geniuses. But the main [goal] is that we've chosen well-rounded, well-behaved, professional people who are adaptable and resilient."

THE FIRST Americans to go to space in the 1960s were test pilots, in part because test pilots were a ready-made group of people who were used to undertaking uncomfortable and potentially dangerous flight missions. They even had experience wearing claustrophobia-inducing helmets, which Cathleen Lewis, a curator at the Smithsonian's National Air and Space Museum, says is a surprisingly important criterion: "If you've [never] had the opportunity to put either a space helmet or a flight helmet on your head, it is very constrained."

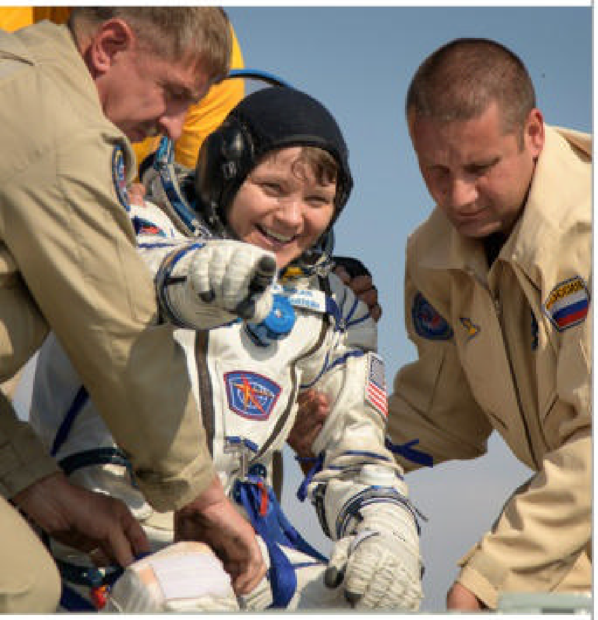
In addition to test-pilot experience, the first American astronauts needed to be under the age of 40, have a bachelor's degree and be shorter than 5'11" to physically fit into the Mercury capsule, though the candidates had already met that requirement in order to become test pilots. Those selected were run through a gamut of intense and invasive physical and psychological tests, made famous in the book (and later, film) *The Right Stuff*. For instance, in the book, author Tom Wolfe describes everything from electric shocks to barium enemas.

Meanwhile, over in the Soviet Union, the cosmonauts had their own selection process. After World War II, most of their tried-and-true test pilots were helping to design new aircraft, so the people selected for the cosmonaut

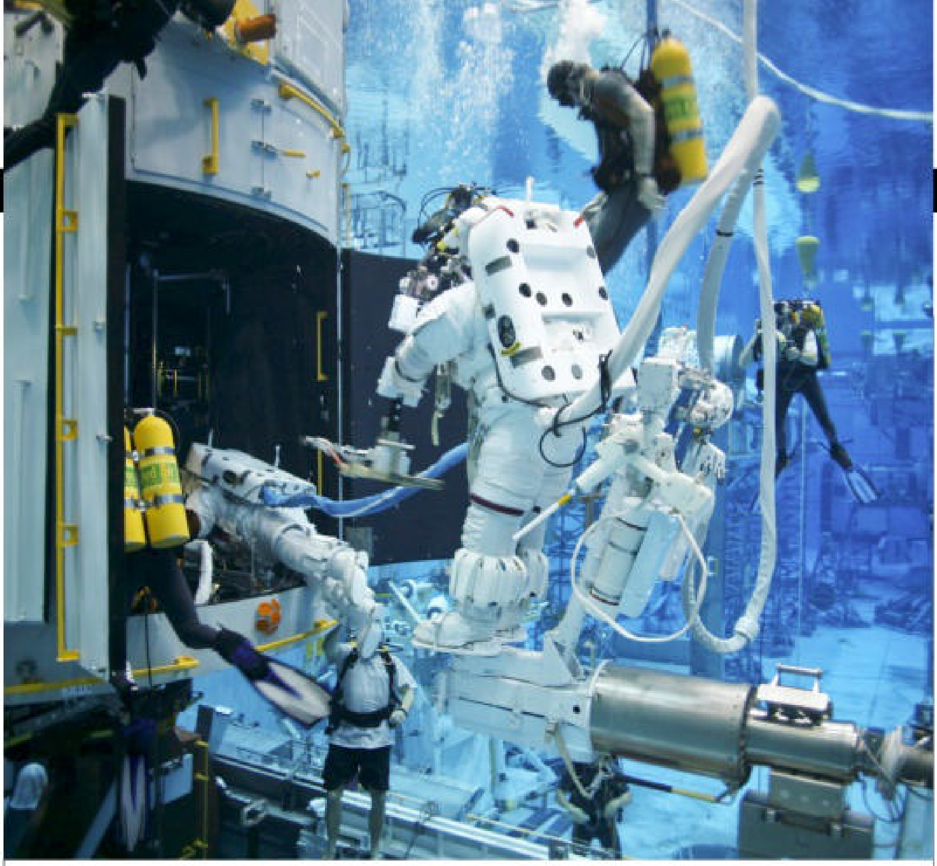
CLOCKWISE FROM TOP LEFT: NASA; NASA; NASA/BILL INGALLS

program were often newly minted lieutenants in the Soviet Air Forces. They were smaller, on average, than American astronauts, with a height limit of just 5'7". Another big difference between the cosmonaut and astronaut programs was the role of women within them: According to Lewis, the Soviets wanted to "demonstrate that they had 'mastered this so well that even women can do it.'" Cosmonaut Valentina Tereshkova became the first woman in space in 1963, a full 20 years before American Sally Ride.

The first U.S. astronauts weren't just entirely men — they were also all white. While NASA didn't explicitly ban people of color from becoming astronauts at the time, "by virtue of the history and the systemic racism of the preceding agencies, yes, they excluded minorities," says Lewis. There were some Black astronaut candidates as early as 1963, but the first Black astronaut from the U.S. to reach space was Guion Bluford in 1983.



NASA ASTRONAUT Anne McClain climbs out of the Soyuz MS-11 spacecraft.



IN THIS MASSIVE water tank at Johnson Space Center, astronauts work underwater to simulate the experience of weightlessness.

JUST AS THE missions for astronauts have changed, so too have the selection criteria. In the earliest missions, we didn't know what space travel would do to the human body; therefore, the selection and training processes erred on the side of caution by putting candidates through physical extremes. Modern missions, however, are more like working in a scientific laboratory — albeit one with extra rigors.

"We're lab techs; we're the hands and the feet of the investigators who invested years and millions of dollars in getting their experiments up there," Barratt says. "But just remember that we're doing it all in weightlessness, and we're doing orbits, 70,500 miles an hour."

There are no age limits to becoming an astronaut, no previous flight experience is necessary and the physical requirements are less demanding than they were in the days of the Mercury and Gemini missions. For instance, modern astronauts aren't required to train in a spinning gimbal rig because they're no longer sent up in erratically spinning capsules.

Still, Barratt says, "we don't want a couch potato." Astronaut candidates undergo tests for strength, agility and endurance, like riding an exercise bike with an increasing workload until the candidate is exhausted. NASA physicians also take family medical histories to make sure there aren't any hereditary issues that might crop up during a mission. All in all, though, "aerobic fitness varies pretty widely in the corps because that's one of many, many factors that makes you successful," Barratt says.

Despite the rigors of the astronaut-selection process, the most important part just might be finding candidates with the right personality. The ability to "function under stress or to handle something that's uncomfortable or new or unpredictable and stay steady — that's really what we're looking for," Barratt says.

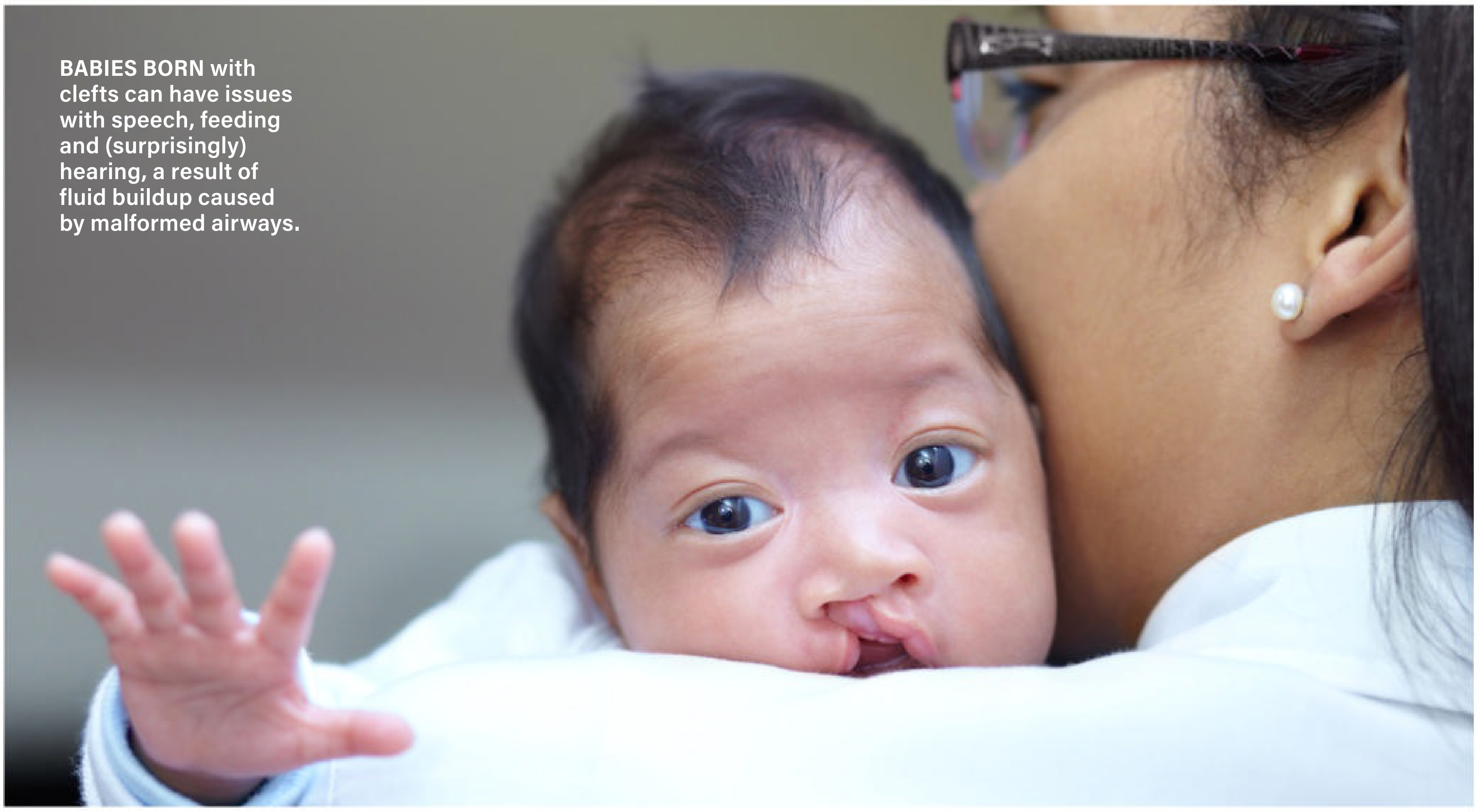
"Teamwork is probably the No. 1 competency that we pay a lot of attention to," agrees Anne Roemer, NASA's astronaut-selection manager. A group of around 120 candidates is invited to come for in-person interviews, and then a smaller subset typically undergoes a second round of interviews, she says. "We have the opportunity to get down to that final group just to run simulations with them and see how they actually perform."

Barratt says that the astronaut hopefuls' CVs and interviews are helpful tools for finding the right people, but some of the most valuable insights into personality come across when the astronaut candidates are living together during the training process: "Somebody who takes out the trash without being asked or does the dishes without being asked, that's a pretty positive sign." — KATE GOLEMBIEWSKI

Aspiring Astronauts

NASA'S WEBSITE LISTS THE FOLLOWING CRITERIA FOR ASTRONAUT HOPEFULS:

- Be a U.S. citizen.
- Possess a master's degree in a STEM field, including engineering, biological science, physical science, computer science or mathematics, from an accredited institution.
- Have at least two years of related professional experience obtained after degree completion or at least 1,000 hours pilot-in-command time on jet aircraft.
- Be able to pass the NASA long-duration flight astronaut physical.



BABIES BORN with clefts can have issues with speech, feeding and (surprisingly) hearing, a result of fluid buildup caused by malformed airways.

THE SCIENCE OF CLEFT LIP AND PALATE

AROUND 1 IN 700 CHILDREN ARE BORN WITH THE BIRTH DEFECT EACH YEAR. HERE'S WHAT YOU NEED TO KNOW ABOUT HOW CLEFTS FORM, WHAT CAUSES THEM AND HOW THEY CAN BE REPAIRED.

WHEN I WAS BORN, two tiny gaps — no more than a few millimeters across — split apart my upper lip and the roof of my mouth. My parents had known about this craniofacial anomaly at least several weeks before my birth, thanks to a routine ultrasound. Over the course of the next few decades, I would undergo countless surgeries, from complicated orthodontic procedures to jaw-breaking bone grafts.

My experience is hardly unique. One in 700 to 1,000 babies are born with either (or both) a cleft lip and/or cleft palate, which occurs when the lip or mouth doesn't properly fuse during early pregnancy. "Cleft lip and palate is one of the most common congenital birth defects," says Janice Lee, clinical director of the Craniofacial Anomalies and Regeneration Section of the National Institute of Dental and Craniofacial Research. "It's a separation in the lip and nose, and in the palate. And there's a gap between the mouth and the nose."

This seemingly small gap can cause big problems. For starters, says Lee, it can pose issues with feeding, as babies born with clefts aren't able to form a seal with their mouths. Speech difficulties can also arise, since the palate is crucial in forming certain sounds. And some may struggle with stigmatization from others due to such a visible facial difference, particularly in lower-resource communities where surgery isn't always an option.

Despite their prevalence, there's plenty that people don't know about clefts. "A lot of people don't know how common they are," says Brent Collett, a pediatric psychologist at Seattle Children's Research Institute who studies young children with craniofacial conditions. "There are a lot of babies who are affected by this."

DURING THE EARLY stages of pregnancy — when an embryo is no larger than a grain of rice — both body tissue and specialized cells from each side of the head grow towards the center until they join together. "Facial development occurs at six weeks in utero," says Lee. This fusion forms our facial features, like the lips, nose and mouth. (In this sense, everyone starts out with a cleft lip and palate.) But when those tissues don't fuse, it can result in a cleft lip, when the upper lip doesn't form properly, and/or cleft palate, when the roof of the mouth doesn't close.

Clefts have likely been around for a long time; King Tutankhamun, for instance, suffered from a partial cleft palate. Throughout history and across

PEOPLEIMAGES/ISTOCK VIA GETTY IMAGES

cultures, many have tried to suss out what, exactly, causes their occurrence. One theory among traditional Hindu and Muslim healers posits that if a pregnant woman carries a sharp object during an eclipse, her infant could be born with a cleft. Even today, some cultures view the condition as divine punishment for parental sins.

But scientists still don't know precisely what leads to clefts. Most researchers believe that they're caused by a cocktail of genetic and environmental factors. "A lot of things can cause it," says Lee, who adds that scientists are continuously identifying new genes that may be associated with clefts. In a 2019 study published in *Science Advances*, researchers identified more than 100 new genes that could lead to the development of cleft lip and palate.

Environmental factors likely play a role, too. Scientists know that smoking, diabetes and certain medicines used to treat epilepsy can boost a parent's risk of having a baby with a cleft.

THERE'S NO "one-size-fits-all" approach when it comes to repairing clefts. Still, Lee says that in the U.S., the surgical trajectory is pretty consistent. "Most babies will have their cleft lip repaired first, and that allows them to [make a] seal properly, and that continues before the baby is six months old," she says. "And then the baby will undergo cleft palate repair, usually around a year old; you want them to have that seal in the palate so there isn't air escaping between the palate and the nose." As the child grows, they'll typically undergo a series of orthodontic treatments, and may need additional surgeries, as well. Some adults born with a cleft have had more than 10 operations on their mouth, nose and jaw throughout their life.

> Researchers identified more than 100 new genes that could lead to the development of cleft lip and palate.

SCIEPRO/SHUTTERSTOCK

Those years of intensive procedures add up — total lifetime treatment costs can range from $100,000 to $200,000 per person. Plus, beyond the needs of surgical care, individuals with clefts may also have an increased risk for certain diseases like breast and lung cancer, and tend to experience more learning difficulties as young children.

Even when facing these hurdles, with treatment, most children with clefts are able to lead happy and healthy lives. "Having a congenital birth defect really doesn't define you," says Lee. "That's so important for families to know and feel; there are teams that want to support the whole family. And we hope that there are noninvasive therapies in the future so that kids don't have to go through multiple surgeries."

For cleft patients who have had scores of surgeries throughout their lives, it's important to remember that each treatment represents another step in a longer journey. A few years ago, I was delighted to get new prosthetic front teeth after a major surgical repair the previous summer. Before, like many with clefts, I sometimes smiled without showing my teeth. Now, I'm much more likely to flash a toothy grin whenever someone pulls out a camera. — ALEX ORLANDO

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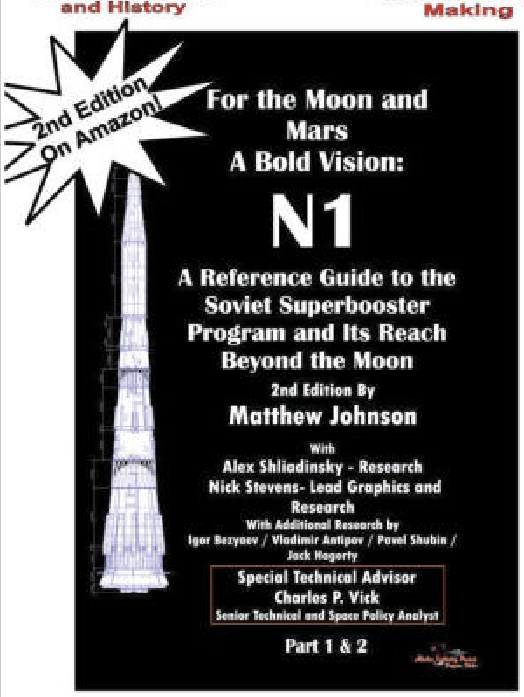

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THIS 3D rendering of *Dilophosaurus* shows off the striking crests atop its skull. Fittingly, the Early Jurassic predator's genus name means "two-crested lizard."

DANIEL ESKRIDGE/SHUTTERSTOCK

Could Usain Bolt Outrun a *Dilophosaurus*?

A PHYSICS PROFESSOR PITS THE FASTEST HUMAN ALIVE AGAINST THE PREHISTORIC PREDATOR MADE FAMOUS BY *JURASSIC PARK*.

IF YOU WERE just going by the 1993 blockbuster *Jurassic Park*, you might think that the dinosaur *Dilophosaurus* was pretty spry. In a now-infamous — and scientifically dubious — scene, the Early Jurassic predator dodges behind a tree while playfully evading one of the film's villains. Moments later, it scurries up a stream of cascading water (offscreen) before popping up to unfurl its neck frill and spit venom in the man's face.

Paleontologists know that *Dilophosaurus* didn't have colorful neck frills, nor did they spew black goo to subdue their prey. And while the double-crested creature is depicted as roughly human-sized on screen, it actually weighed a whopping 900 pounds and spanned just under 20 feet in length some 190 million years ago. Still, the filmmakers may have been onto something regarding the therapod's agility — thanks to its powerful legs, it could reach speeds of over 20 mph.

But was *Dilophosaurus* fast enough to beat eight-time Olympic gold medalist Usain Bolt in a 100-meter dash?

While it may sound like a strange hypothetical, that's the question that University of Toledo physicist Scott Lee posed to his undergraduate students in introductory physics, according to a paper published in *The Physics Teacher* last year. "I'm always looking for new and interesting things that will excite the students," says Lee. "Everyone, at some point in their life, has been interested in dinosaurs, so I try and bring [these] concepts [into the classroom]."

LIKE MANY OTHER dinosaur aficionados, Lee's fascination with the prehistoric beasts started at a young age, ever since he began finding fossils with his family growing up. Years later, in the early 1990s, he found a book by zoologist Robert McNeill Alexander — *Dynamics of Dinosaurs and Other Extinct Giants* — that uses physics principles to theorize how dinosaurs might have moved throughout the world.

Plenty of other scientists have been just as fascinated by the biomechanics of dinosaur movement — particularly when it comes to calculating the running and walking speeds for prehistoric touchstones like *Tyrannosaurus rex*. For example, one study published in 2017 calculated that *T. rex* could only reach a maximum speed of around 12 mph; any faster, the researchers speculated, and the predator's bones would have shattered. More recently, scientists created a 3D reconstruction of a *T. rex* tail to calculate that the animal likely lumbered along at just under 3 mph, according to a paper published in *Royal Society Open Science* in 2021.

Lee points to the variety of approaches that researchers can use to model such predictions. "We have the bones from many dinosaurs; with the *Dilophosaurus* and *Tyrannosaurus rex*, we have essentially complete skeletons," he says. "By looking at modern animals, you can then get an idea of how big the muscles were to then calculate how big of a force you could apply to the leg of a dinosaur to […] model how fast it would go." Other researchers have used robotics to model their predictions. "But, of course, this is just theoretical work," Lee adds. "We don't have any actual proof that these models work when it comes to dinosaurs."

CELSO PUPO/SHUTTERSTOCK

> The students concluded that Bolt would easily outstrip *Dilophosaurus*, leaving it in the dust by two seconds.

FOR MANY STUDENTS just starting to learn about physics, the difference between speed and acceleration isn't always intuitive. "They tend to think of that as being the same thing — if you accelerate fast, you're going to go fast," says Lee. "Well, that's true, but they're actually very distinct concepts." In preparing his exercise, Lee wanted to create a situation where the speed between two subjects was roughly the same, but because the accelerations were different, so was the outcome. After that, the race was on.

In tackling the exercise, the students applied concepts of kinematics — like displacement, speed, velocity and acceleration — while modeling the race using spreadsheets. They ultimately concluded that Bolt would easily outstrip *Dilophosaurus*, leaving the Early Jurassic predator in the dust by two seconds.

As Lee emphasized to his class, the key factor was indeed acceleration. Following Newton's second law of motion, where acceleration is dependent upon an object's mass and force, Bolt's smaller size would give him an early leg up. "*Dilophosaurus* has bigger muscles and can generate a bigger force, but that force goes up against the cross-sectional area of the muscle," says Lee. "So the bigger something gets, yes, it becomes stronger, but its acceleration becomes less. That's why *Dilophosaurus*, because it's so much more massive than Usain Bolt, accelerates a lot slower."

— ALEX ORLANDO

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The Sugar Scientist Revolutionizing Health Care

NOBEL-PRIZE-WINNING CHEMIST **CAROLYN BERTOZZI** INVENTED A NEW FIELD THAT TRANSFORMED HEALTH CARE AND CANCER TREATMENT.

BERTOZZI WAS awarded the 2022 Nobel Prize alongside chemists Morten Meldal and K. Barry Sharpless.

COMPARED TO the pristine flask in a sterile lab environment, cells in the body are messy balls of chemical soup. This means that chemical reactions invented in a lab often fail in the body.

In the late 1990s and early 2000s, Stanford University chemist Carolyn Bertozzi developed a suite of reactions that work quickly and efficiently, even in a messy cellular environment. She named the field bioorthogonal chemistry, which has since helped scientists make major breakthroughs in biological research, medical imaging and drug delivery. In 2022, she was awarded the Nobel Prize in chemistry for her work.

“Orthogonal means ‘not interacting,’ and bioorthogonal means ‘not interacting with biology,’ ” Bertozzi says. “With all of the proteins and nucleic acids and blood components and tissues, and all this stuff, these two molecules ignore them all and react with each other to form a product.” Bertozzi likens the chemical reactions she developed — which enable scientists to study molecules and their interactions in living things without disrupting natural cellular processes — to two soulmates meeting at a party.

“It’s like there’s a crowded room of people buzzing around, and two people might find each other from across the room. All of a sudden, everyone disappears and they, you know, react with each other.”

Since bioorthogonal chemistry can help penetrate the body without altering it, it opens up endless possibilities for medical imaging and drug delivery. From inside the body, the molecules can tag and track other compounds of interest. In mice, for example, bioorthogonal reactions can highlight tumors during PET scans. What’s more, they can react at targeted sites, localizing drug delivery. This avoids harmful side effects that arise from full-body delivery of a drug.

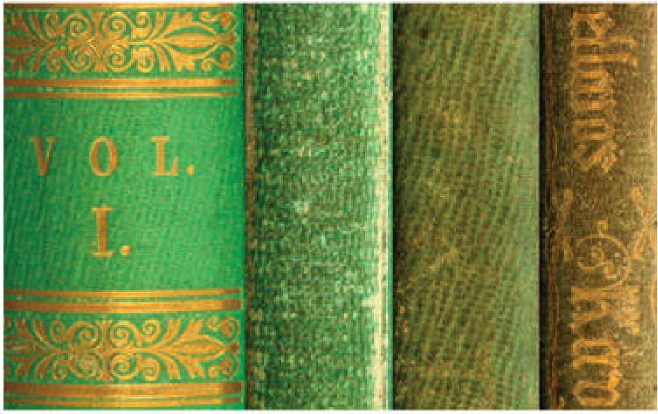
Despite the transformative impact of her work, Bertozzi remains captivated by the basic chemistry behind it. Cells are covered in sugars, or glycans, and their function bewildered scientists for decades. Bertozzi developed bioorthogonal chemistry initially as a tool to study them. “It had been reported for 70 years that glycans populate the surfaces of cells, and those structures change when a cell is part of a tumor,” Bertozzi says. Healthy cells have a neat glycan layer that resembles a well-manicured lawn, whereas tumor cells have a messier, overgrown layer of glycans.

Bertozzi’s team discovered that glycans on tumor cells are a survival mechanism. “They actually grab onto receptors on immune cells that send a signal for them to sleep,” she says. “We used bioorthogonal chemistry tools to figure that out.” Like much of the lab’s work, the finding could lead to new cancer treatments. Palleon Pharmaceuticals, which Bertozzi advises, developed a drug that trims the tumor cell’s overgrown glycan layer like a lawnmower. Clinical trials began in March 2022.

—JASON P. DINH

DO PAM/STANFORD UNIVERSITY

TENS OF THOUSANDS OF BOOKS BOUND IN EMERALD GREEN BETWEEN THE 1840s AND 1860s ARE LACED WITH ARSENIC. A GROUP OF CONSERVATORS IS WORKING TO TRACK THEM DOWN.



BEWARE THESE POISON BOOKS

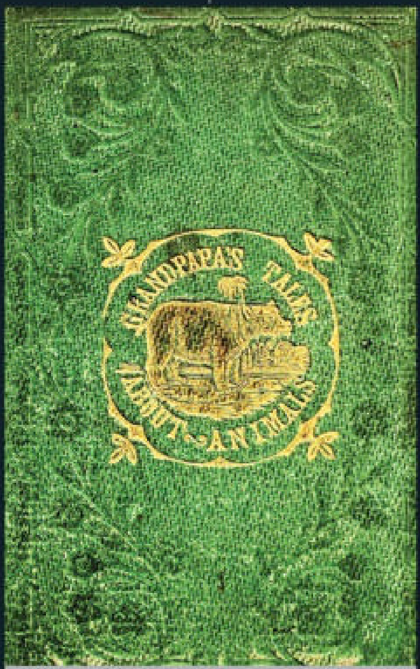
NOWADAYS, we tend to give arsenic a wide berth — the element isn't known as the "king of poisons" for nothing. Its toxicity stems from its similarity to the life-sustaining nutrient phosphorus, which allows arsenic to invade important chemical reactions in the body and disrupt them. The element is also happy to mix with others, often forming deadly compounds with no taste or smell. Yet this versatility is what made arsenic so ubiquitous in a variety of Victorian-era products, from home decor and wallpaper to clothing and books. When arsenic trioxide is combined with copper acetate, it produces an eye-catching compound called copper acetoarsenite, or emerald green.

"At the time, emerald green was a wildly popular color among consumers," says Melissa Tedone, a conservator at the Winterthur Museum, Garden and Library in Delaware and lead conservator for the Poison Book Project, an ongoing project to investigate Victorian-era book bindings. "No alternative dye could even come close to the intensity of the color."

IN BOOKBINDING, its use as colorant allowed arsenic to spread far and wide; Tedone estimates that as many as tens of thousands of books were bound in emerald green between the 1840s and 1860s. Although a series of accidental arsenic poisonings sparked debate over the substance's safety toward the end of the era, she says, it's unlikely that manufacturers would have been quick to give up the hue as long as there was strong demand for it.

So, in 2019, Tedone and her colleagues began testing hundreds of books from Winterthur and the Library Company of Philadelphia. About half of these contained lead; some others revealed different heavy metals, such as chromium and mercury. But just over 10 percent of the green-colored books were found to contain arsenic — a much larger health risk for librarians, collectors and researchers.

That hazard is not only due to arsenic's toxicity, but because the powder tends to flake easily from a binding and into the air when disturbed. "The arsenic offset is invisible to the naked eye," explains Tedone, "so a person handling an arsenical book wouldn't necessarily see any green pigment offsetting onto their hands or other surfaces."



AN EMERALD green bookcloth adorns this 1850 imprint. While parts of the front and spine have browned over time, likely due to air pollution, the cloth cover remains vividly green.

In response, the conservators kickstarted the Poison Book Project, focusing on tracking down books bound in potentially toxic pigments. They use a number of nondestructive techniques to identify arsenical books without causing damage to them: X-ray fluorescence spectroscopy detects arsenic and copper, while a second method called Raman spectroscopy can confirm the presence of emerald green.

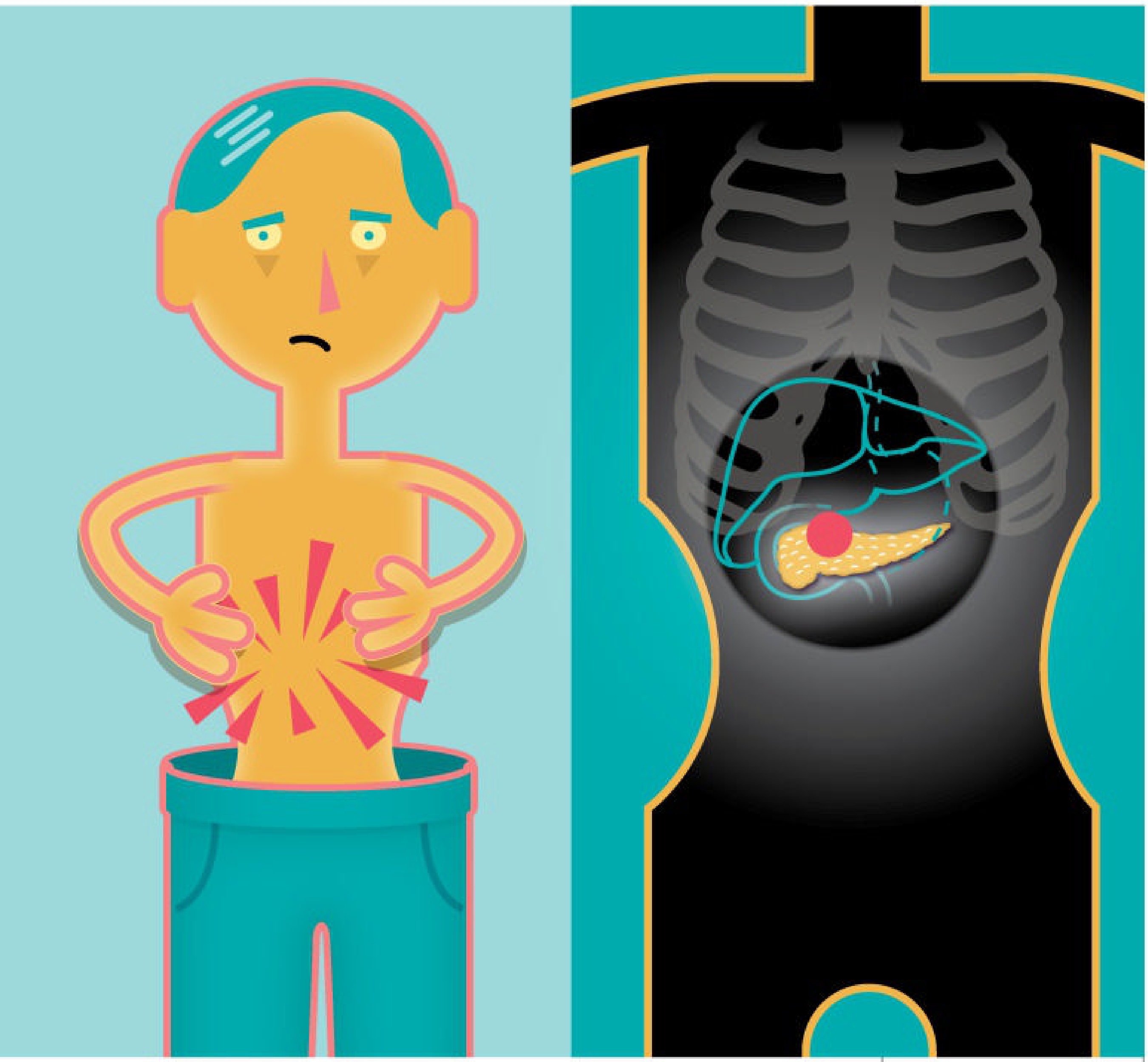
Thanks to the work of researchers from more than a dozen other institutions and private collections, 124 arsenical books have so far been identified, Tedone says. To help in the tremendous undertaking, the Poison Book Project distributes bookmarks with safety warnings and images of various emerald green colors. As of August, the project had distributed more than 1,500 bookmarks to 49 states and 19 countries around the world.

While nothing short of licking a toxic tome would lead to a serious case of arsenic poisoning, exposure to copper acetoarsenite particles can still irritate the eyes, nose and throat. For librarians and researchers, repeated interactions may cause more serious internal symptoms such as dizziness and nausea.

If you suspect you might be handling a Victorian-era book bound in emerald green, make sure to wear nitrile gloves, avoid touching your face and wipe down all surfaces after you are done. (You can even request a specialized color swatch bookmark from the Poison Book Project, just to be sure.) — MARISA SLOAN

FROM TOP: WINTERTHUR LIBRARY/PRINTED BOOK AND PERIODICAL COLLECTION; MELISSA A. TEDONE

BY DOUGLAS G. ADLER



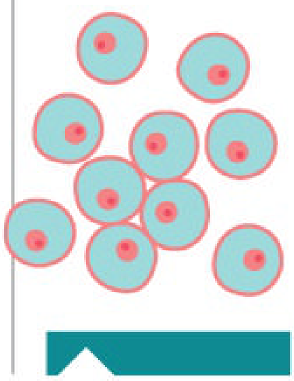
Not-So-Mellow Yellow

HIS SICKLY SKIN COLOR, POOR APPETITE AND SIGNIFICANT WEIGHT LOSS ALL SCREAMED PANCREATIC CANCER. WHAT ELSE COULD IT BE?

The buzz of my pager alerted me that the Emergency Department needed a gastroenterologist. Even from 20 feet away, I could tell that the patient, James, was deeply jaundiced: His skin and eyes were both an unhealthy shade of yellow. He also looked thin and sickly in a way that suggested he was chronically ill.

After I introduced myself, James, a retired aerospace engineer in his 70s, told me his story: For about a month he had been feeling weak and run down, with a poor appetite. He would eat a few bites and, despite feeling hungry, be unable to continue. Such complaints are common in cancer patients of his age, and serve as alarm symptoms to doctors. James also had a gnawing pain in his stomach that worsened when he ate. This, in turn, made him eat even less. His wife Ellen, who was at his side, told me that he had lost about 30 pounds. (He even had to buy new pants, as his old ones were literally falling off his waist.) When I asked James if the pain while eating went anywhere else in his body, he told me it felt like it shot straight through to his back.

James also had a gnawing pain in his stomach that worsened when he ate. This, in turn, made him eat even less.



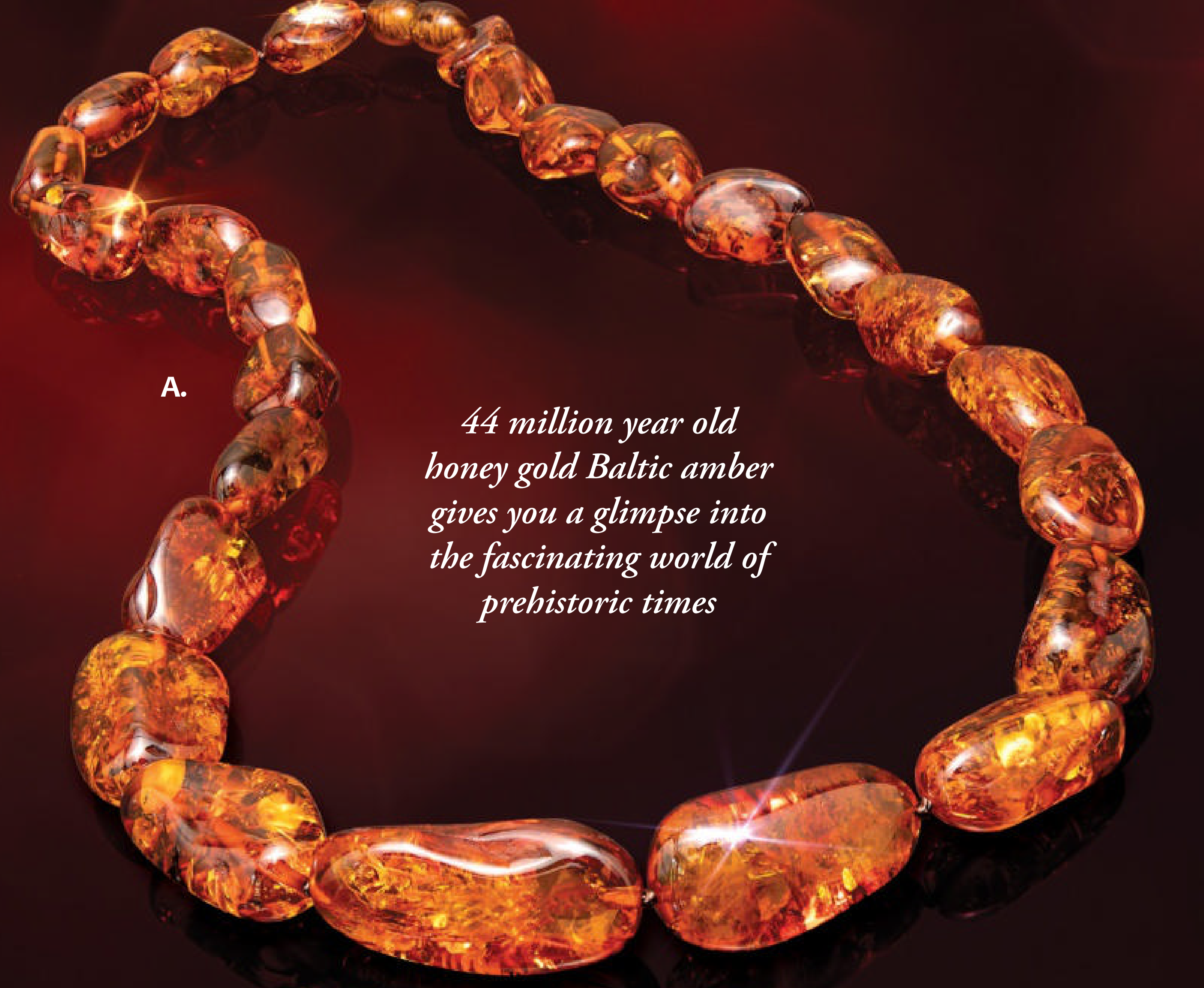
James was describing a concerning constellation of symptoms. Everything brought a single, unifying diagnosis to mind: pancreatic cancer. Despite decades of research into better medicines and surgical techniques, around 90-95% of patients with pancreatic cancer succumb to the disease within five years of being diagnosed.

The pancreas makes enzymes that do the work of digesting your food so your body can absorb it after you eat. The organ also makes many hormones, such as insulin, which regulates the body's blood sugar levels.

Pancreatic cancer often leads to jaundice when a tumor encases and obstructs the bile duct, which carries bile from the liver to the intestines. Normally, bile helps break down and absorb the fat in our diet. But when the duct gets blocked, the bile backs up into the bloodstream and changes the color of a patient's skin and eyes — even their urine, which takes on a dark, "tea-colored" hue. Abdominal pain that radiates to the back is also classic for pancreatic cancer, as are weight loss and poor appetite. Other illnesses can cause these symptoms, but I was pretty sure we had the diagnosis pegged.

I ORDERED A CT scan of James' abdomen, and it confirmed my fears. A 3-centimeter mass in the pancreas appeared to be obstructing the bile duct — a distressingly common finding among patients with pancreatic cancer. James was admitted, and the next day I performed two endoscopic procedures on him. First, I inserted a stent into his obstructed bile duct to keep it open and allow the backed-up bile to drain, resolving his jaundice, and took a tissue biopsy from the inside of the bile duct. Next, I used an endoscope with a built-in ultrasound machine to look at the mass in the pancreas and take multiple additional biopsies of the lesion itself.

KELLIE JAEGER/DISCOVER (2)



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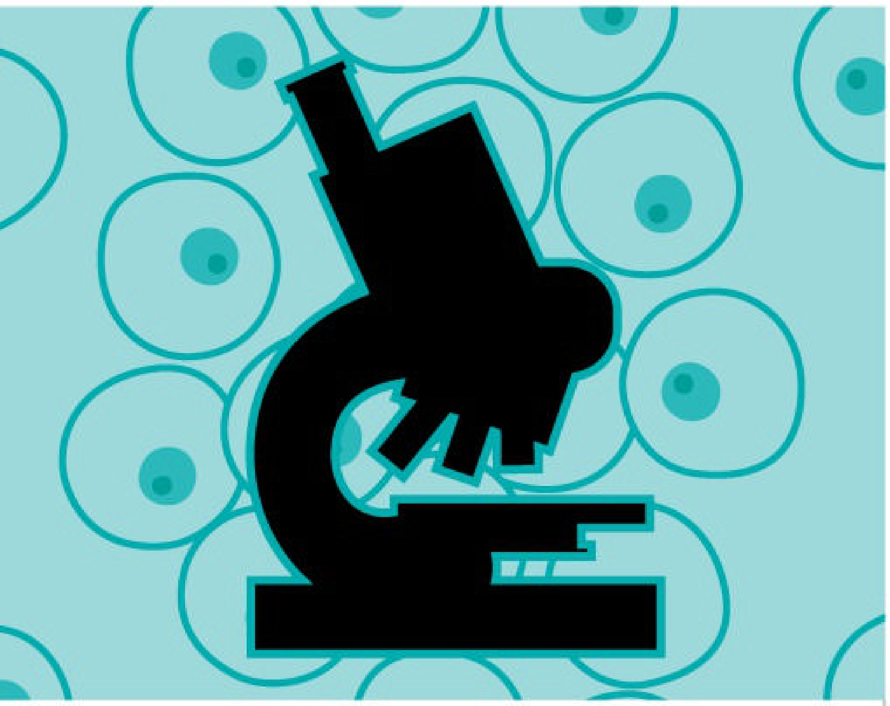


Poring over the CT scan one more time, I saw that James had a few subtle lesions in both kidneys that hadn't been noticed.

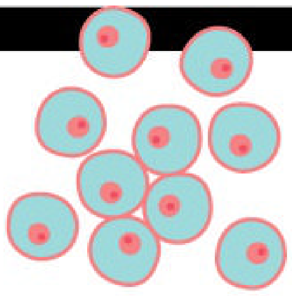
The mass looked somewhat atypical for pancreatic cancer, but it was concerning nonetheless. Afterward, I told James and Ellen to be prepared for the (very real) possibility that the biopsies would show cancer. Upon hearing the news, James responded with stoic silence; Ellen became red-faced and tearful. Both exchanged worried glances.

But when the results were available, I was surprised to see that they did not, in fact, show cancer — only benign tissue. Still suspicious, I reviewed the results with James and told him that while a positive biopsy confirms cancer, a negative result like this doesn't necessarily rule it out. I told him that we needed to repeat the biopsy. By that point resigned to his fate, James listlessly agreed.

The next day, I repeated the same procedures, including biopsies of the inside of the bile duct and the mass itself. Several days later, the biopsy results returned, again showing only benign tissue. A quick phone call to the pathologist reassured me that the slides had been read correctly.

It seemed likely that cancer wasn't the culprit. Chronic pancreatitis, a condition often caused by heavy alcohol use, is known to sometimes mimic pancreatic cancer — and is itself a risk factor for the disease. It can also cause many of the same symptoms that James was experiencing. Still, his CT scan certainly did not look like he had chronic pancreatitis. Poring over it one more time, I saw that James had a few subtle lesions in both kidneys that hadn't been noticed by the radiologist interpreting his films.

Kidney lesions in the presence of a pancreatic mass pointed to a different diagnosis altogether, a condition known as autoimmune pancreatitis. As the name suggests, autoimmune pancreatitis is not cancer at all. Rather, it's a disorder in which the body's own immune system attacks healthy tissue by mistake. Autoimmune pancreatitis is relatively rare and, despite its name, often affects other organs besides the pancreas — frequently the kidneys. It can also produce lesions that can closely mimic malignant tumors, obstructing the bile duct and closely replicating the signs and symptoms of pancreatic cancer. A critical distinction, however, is that autoimmune pancreatitis can be treated with medications.



WHEN I PRESENTED all of this to James, he was skeptical. I had made my worries about cancer so clear that he had a hard time believing it could be anything else. I suggested blood tests to measure the level of certain antibodies which can suggest autoimmune pancreatitis, and he agreed. Sure enough, the level was markedly elevated.

As with many autoimmune diseases, the treatment for James' condition includes medications to reduce the activity of the immune system. This regimen sounds simple, but in practice, it can be tricky: too little reduction in activity and the patient does not get better. Too much puts the patient at risk for infections, as the weakened immune system may not be able to respond to invading bacteria or viruses. I started James on a course of high-dose steroids to "turn down the volume" on his immune system, planning to taper the dose over the coming weeks.

One month later, James came to my clinic for a follow-up; I almost didn't recognize him. He had gained nearly 20 pounds, his appetite was healthy and his pain was gone. His energy had also returned. What's more, a CT scan showed that his pancreatic lesion had disappeared, as had the spots on his kidneys, solidifying the diagnosis. (Pancreatic cancer does not respond to steroids.) A few weeks later, I was able to remove the stent from his bile duct.

Patients with autoimmune pancreatitis are at high risk for relapse, so I planned to see James back periodically. Not everyone with a chronic autoimmune disease would consider themselves fortunate. But with pancreatic cancer as the alternative, James was definitely one lucky man. D

***Douglas G. Adler** is a gastroenterologist and director of the Center for Advanced Therapeutic Endoscopy in Denver. The cases described in Vital Signs are real, but names and certain details have been changed.*

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BY SARAH SAX

AROUND A THIRD of the Cerrado's roughly 12,000 plant species are endemic, meaning they're found nowhere else on Earth.

The Invisible Biome

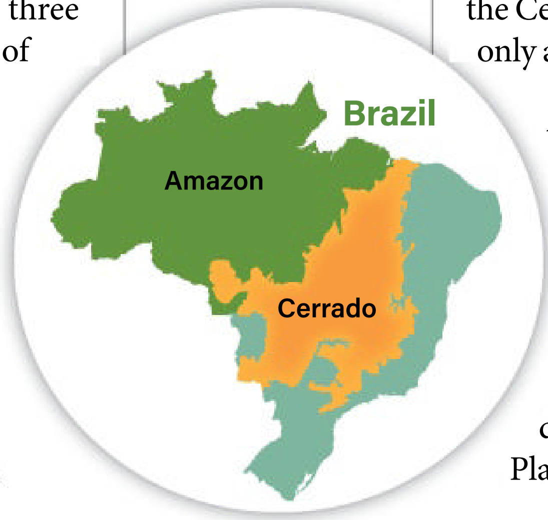
SOUTH AMERICA'S LARGEST SAVANNA, LYING IN THE SHADOW OF THE AMAZON RAINFOREST, IS AN UNEXPECTED RESERVOIR OF BIODIVERSITY.

To the untrained eye, Brazil's savanna seems a bland expanse of brown grasslands, woody shrubs and wizened trees abutting the lush Amazon rainforest. The region, called the Cerrado, is tormented by harsh environmental conditions: acidic soils, long periods of low precipitation and frequent wildfires. Yet it is precisely these conditions that have encouraged unique and highly specialized organisms to form.

When Mercedes Bustamante first came to the Cerrado three decades ago, she was fascinated by its hidden abundance of life: The region is home to almost a third of the species found in Brazil and around 5 percent of all global species. "The Cerrado is the most diverse savanna in the world," says Bustamante, now an ecologist at the University of Brasilia.

During the hot summer months — when the region turns a dusty brown and the dry air causes frequent nosebleeds — Bustamante dons a wide hat over her short brown bob, packs her car with graduate students and drives to one of several experimental plots. The bulk of their work involves studying how changes in the environment alter the amount and types of species growing in the Cerrado. Often, this requires careful measurements of everything from the growth rate of trees to the DNA of microbial communities in the soil.

As the last remaining patches of the Cerrado shrink, so does our arsenal against a rapidly warming world.



But the savanna is rapidly disappearing. The biome is considered one of 36 global biodiversity hotspots — threatened regions with both exceptional concentrations of endemic biodiversity and high levels of vegetation loss. Over the past half-century, industrial agriculture has quietly destroyed around half of the Cerrado's native vegetation. Today, only around 20 percent remains intact.

As the last remaining patches of the Cerrado shrink, so does our arsenal against a rapidly warming world. Modern humans depend on a few dozen crops for nearly all our energy needs, yet most of these crops aren't particularly well-suited to the warmer and drier future that is fast approaching. Plant species already adapted to less

FROM TOP: LUCIANO QUEIROZ/SHUTTERSTOCK; KELLIE JAEGER/DISCOVER

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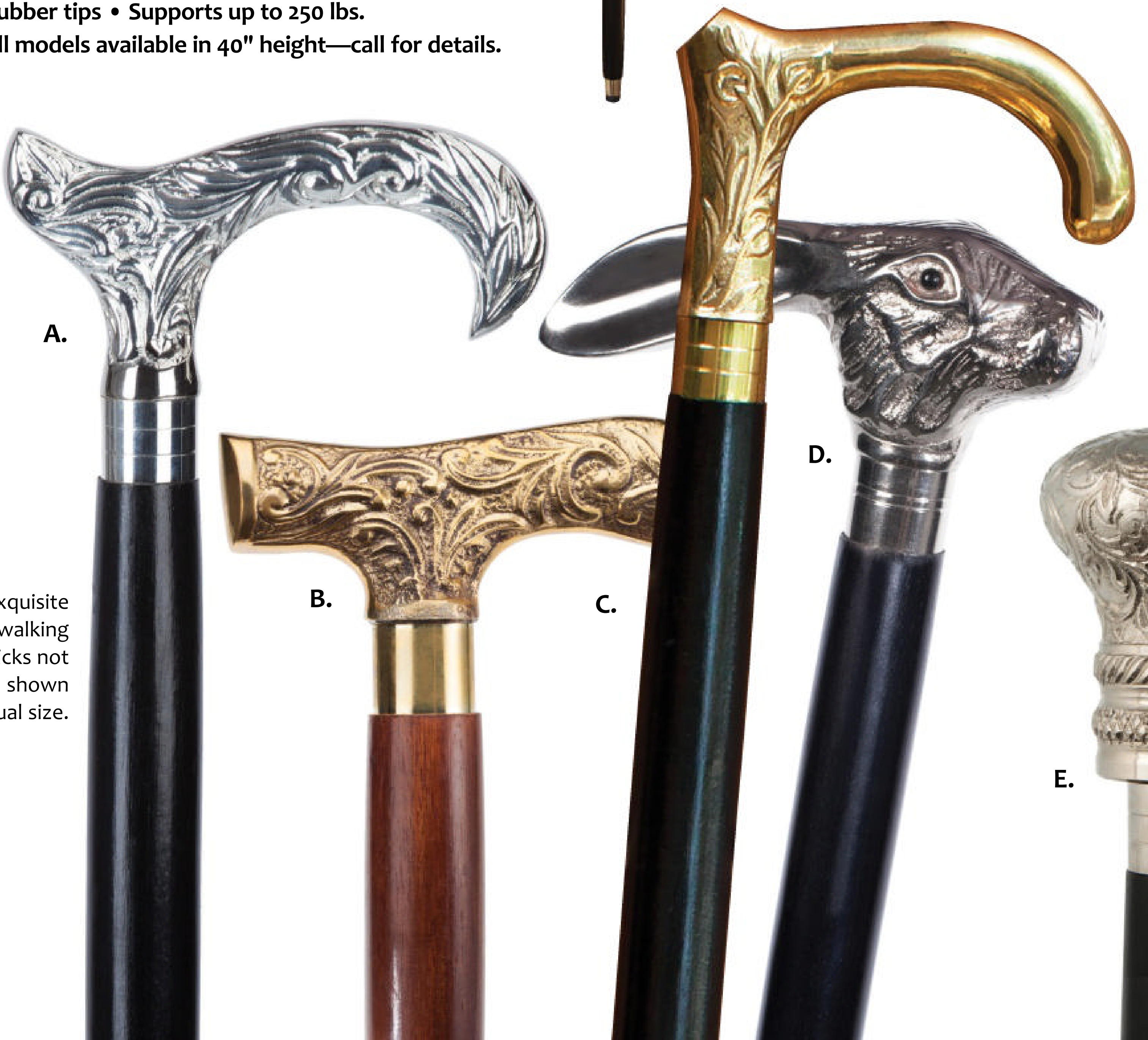
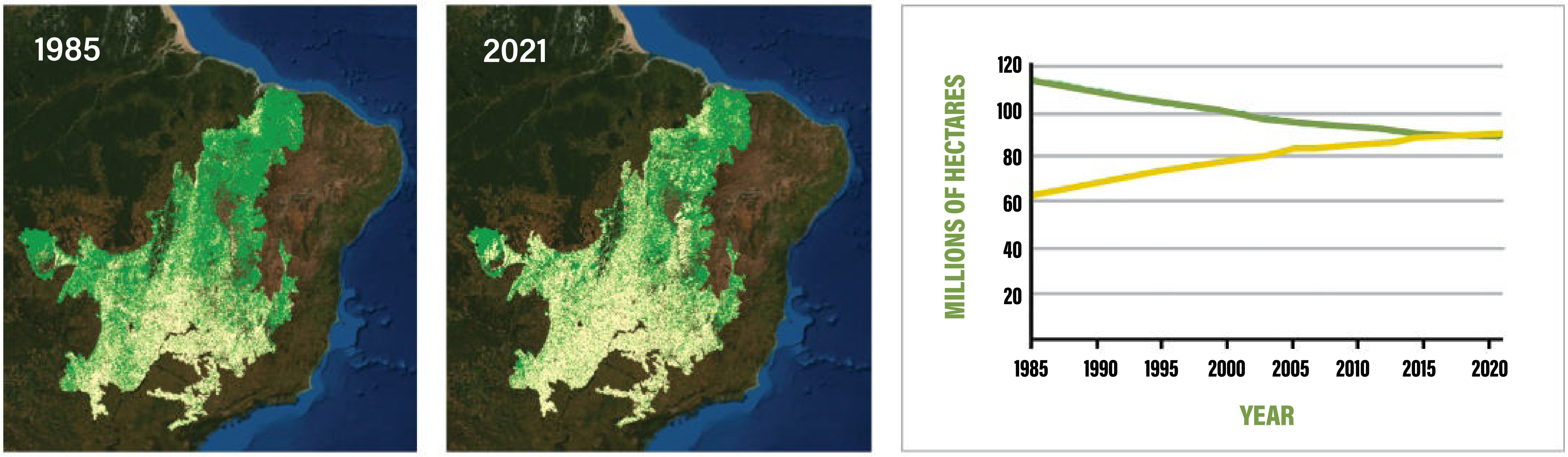


Exquisite walking sticks not shown actual size.



DECADES OF DEFORESTATION

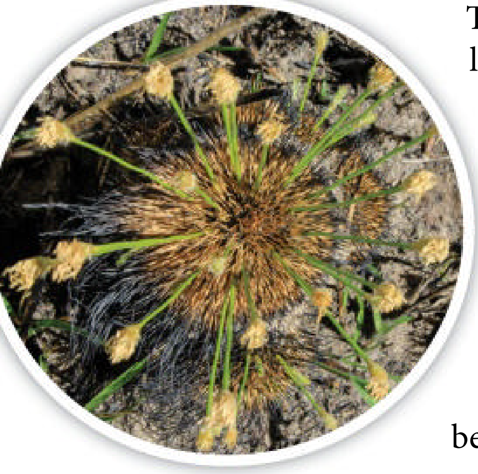
In the Cerrado, the amount of land devoted to agriculture (yellow) exceeded the amount covered by forest (green) for the first time in 2019.

Source: MapBiomas Project, Collection 7 of the Annual Series of Land Use and Land Cover Maps of Brazil

favorable conditions, such as low nutrient levels, extreme weather events, and increased pests and diseases, will be crucial in the coming decades. The question is whether we can halt the destruction of the Cerrado long enough to utilize it.

ONE ADAPTATION Bustamante has extensively studied is the way that some plants deal with high levels of aluminum in acidic soil. Typically, aluminum stunts growth when it builds up in a plant's biomass. Yet in the Cerrado, many common species — including the savanna's most emblematic tree, the evergreen *Vochysia thyrsoidea* — readily absorb and transport the heavy metal to their leaves and seeds. This has significant implications, as soils become more acidic worldwide due to a dangerous combination of intensive agriculture and climate change.

Other plants in the savanna have evolved to thrive in the face of wildfire. *Bulbostylis paradoxa*, a grasslike sedge, blooms (and fast) just after a burn. New vegetation sprouts within 24 hours, and flowers appear within around two weeks of being scorched. More remarkably, because these fires typically occur during the dry season, the plant achieves the rapid growth without water.



This has scientists particularly excited. Because water is scarce for much of the year in the Cerrado, the top few feet of soil is remarkably dry. In response, shrubs and trees barely visible on the surface hide up to 75 percent of their biomass belowground, almost like an iceberg. This allows them to withstand drought much more effectively than their counterparts in, say, the Amazon. It's little wonder that the Cerrado boasts the nickname "the upside-down forest."

Bustamante, now one of the region's foremost experts, isn't the first to puzzle over the fact that extreme environments (like the Cerrado) often lead to extremely diverse species and adaptive strategies. A century and a half before she embarked on her research, the Danish ecologist Eugen Warming also investigated the harshness of the Brazilian savanna. Between 1863 and 1866, Warming roamed around Lagoa Santa in the eastern Cerrado, collecting thousands of specimens — hundreds of which had never been identified.

Warming's close observations of how plants responded and shaped their environment in the Cerrado led him to write several books about plant communities, including his 1895 work *Plantesamfund* (or *Oecology of Plants* in English). The title marks the first-known book devoted specifically to ecology.

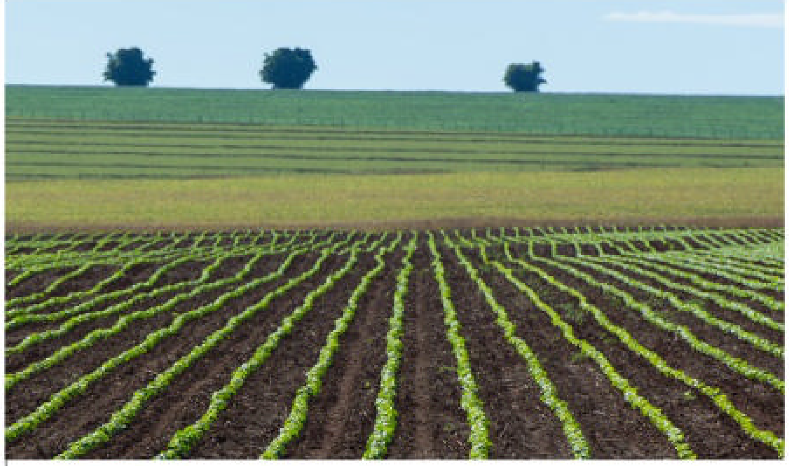
The Cerrado, in many ways, has been more influential to the development of the field of ecology than perhaps any other biome. Yet its trajectory changed dramatically in the 1970s, when the availability of lime, industrial fertilizers and tropical soybean varieties opened the savanna to agricultural expansion. "It was such a good start,"

The Cerrado has been more influential to the development of the field of ecology than perhaps any other biome.

CERRADO SPECIES are well adapted: *Vochysia thyrsoidea* (right) can safely absorb aluminum from acidic soil, and *Bulbostylis paradoxa* (left) can sprout within 24 hours of a wildfire.

FROM TOP: MAPBIOMAS PROJECT - COLLECTION 7 OF THE ANNUAL SERIES OF LAND USE AND LAND COVER MAPS OF BRAZIL, ACCESSED 10/26/22 THROUGH HTTPS://PLATAFORMA.BRASIL.MAPBIOMAS.ORG (3); JOÃO MEDEIROS/CC BY 2.0/FLICKR; TROPICALVISION/SHUTTERSTOCK

says Bustamante. “And then there was complete invisibility.”



Developers cleared some 14 million hectares of native vegetation in the Cerrado between 2006 and 2017 — including 1.75 million for soy fields alone.

WHILE THE AMAZON receives the bulk of concern over deforestation, the Cerrado has borne the brunt of the impact. Developers cleared some 14 million hectares of native vegetation there between 2006 and 2017, almost twice the area of forest loss in the Amazon over the same period. Some 1.75 million hectares were cleared for soy fields alone.

The destruction doesn’t show signs of slowing down. Global food demand could double by 2050; and in Brazil, the Cerrado is well-positioned to satisfy that demand, says David Cleary, director of agriculture at global environmental nonprofit The Nature Conservancy.

As recently as 2017, a group of scientists raised the alarm: In the Cerrado, “a perfect storm of agribusiness expansion, infrastructure development, low legal protection and limited conservation incentives is set to trigger an extinction episode of global significance,” they wrote. Six months later, more than 60 Brazilian and international organizations and institutions published the “Cerrado Manifesto,” calling for companies to stop buying soy and meat products that originated in the Cerrado.

Many activists hoped the manifesto would play out like the 2006 Amazon Soy Moratorium. That marked the first voluntary agreement between industry, government and environmental organizations to forgo buying soy from deforested areas in the Amazon and was widely seen as a success. Within eight years, the legume went from bearing responsibility for 30 percent of annual deforestation in the Brazilian rainforest to less than 1 percent.

But the Cerrado paid the price, according to research that indicates the Amazon moratorium shunted deforestation to the Cerrado. With few places left to expand, farmers and large soy traders in the region are against another such moratorium.

Some alternative spaces for agriculture do exist outside the region, although most experts recognize that accessing them would require massive incentives or regulations. A 2019 study in *Conservation Letters* points to the vast amount of degraded pastureland that could be used to produce crops. Likewise, collecting and selling seeds for savanna restoration has proven to be a sustainable source of income for several communities.

Experts like Cleary, who has lived and worked in the region for more than a decade, see some hope in the way that the Cerrado is, once again, growing in national and international consciousness: “Where the Cerrado is now is really similar to where the Amazon was in the 1980s,” he says.

But until a solution is found, Bustamante says, humans are “burning a library that evolution put there for us.” In a warming world, that could have unanticipated consequences: “We have to find plants that can cope with less water and much harsher conditions — where can we find the solutions?” She fears the answer is rapidly vanishing before our eyes. ◼

AN ESTIMATED 35 to 55 percent of all cattle in Brazil live in the Cerrado. Their pastures together occupy an area roughly the size of France.

Sarah Sax *is a multimedia journalist and producer covering stories about environmental change.*

FROM TOP: AMANDA PEROBELLI/REUTERS/ALAMY STOCK PHOTO; YASUYOSHI CHIBA/AFP VIA GETTY IMAGES; JONNE RORIZ/BLOOMBERG VIA GETTY IMAGES

Beyond ECOTOURISM

BY TREE MEINCH

Across Mexico's Yucatán Peninsula, pools of azure water punch through the landscape like Swiss cheese. In many of these sinkholes, called cenotes (pronounced "seh-NO-tays"), braided root systems and spiraling foliage descend multiple stories down limestone walls to soak in the oases.

Increasingly, however, the flora is sharing these cool waters with throngs of human visitors — swimming, snorkeling or snapping selfies in the otherworldly setting.

Geologically speaking, Mexico's cenotes are entry points to the Yucatán Peninsula's uniquely shallow and vital aquifer. They're entry points for tourists, too, as more and more of these natural marvels are developing into eco-park attractions. And travel access across this region is projected to expand significantly as of 2024, due to an ambitious national train project. But the transportation effort, spearheaded by Mexico's president, Andrés Manuel López Obrador, is generating waves of controversy between local communities, the president and conservationists.

These tensions raise concerns that surface anywhere tourism, development and science collide in the natural world: Humans have the capacity to love wild places to death, degrading them with excessive traffic and misuse; yet tourism also wields the potential to draw funding and support for conservation.

Environmental anthropologist Amanda Stronza has been studying the revolving door between tourism and conservation since her Ph.D. work in the late 1990s. Her career has revealed no simple or perfect template under the umbrella of ecotourism — nor a consistent definition. "Can we harness capitalist forces, and the market, for the good of conservation?" she asks. "It's a double-edged sword."

WHILE THE WORD *ecotourism* was coined in the early 1980s, the concept itself — supporting conservation efforts in part by leveraging nature for leisure and directing revenue back to the ecosystem — stretches back more than a century. The U.S. National Park System was an early originator, designating wild places as protected areas. People pay to visit for relaxation or inspiration, and hopefully they gain appreciation for the flora and fauna that call it home. Ideally, these experiences in turn generate interest in protecting said places, as well as contributing immediate funding to do so.

The dark side, of course, is the potential harm to what you're trying to protect. If you're only considering the land, animals and plants, it's a simple answer. "The activity of tourism is more damaging than no tourism at all," Stronza says. Some ideological purists go so far as to argue that each human must personally avoid flying at all costs, stop consuming goods beyond their immediate community or scrutinize every print they leave on Earth.

However, Stronza adds, that premise ignores a crucial element of reality. "People are part of an ecosystem. They always have been," she says, underscoring how the anthropogenic use of nature stretches back tens of thousands of years. Today's complex economic systems add unique, meaningful opportunities to invest in nature, which can serve humans, animals and landscapes alike. "I care so much about wildlife. But I also see clearly the deep and intimate interactions between people and wild places and wildlife," she says.

For instance, wild places — and new experiences in them — are a well of inspiration. Spending time in nature also is directly linked to improved mental health and physical wellbeing, as well as spiritual practices and other facets of life for many cultures. And history has demonstrated that humans are less likely to invest in protecting habitats and creatures if they share no personal connection to them. One 2016 study even linked the intervention of ecotourism to specific population

AIRPLANE: AVECTOR/SHUTTERSTOCK

A CONSERVATION-MINDED LOOK AT TREADING LIGHTLY — AND RESPONSIBLY — IN SOME OF THE WORLD'S MOST MESMERIZING, VULNERABLE PLACES.

increases in some endangered species, including preventing the likely extinction of orangutans in Sumatra. (Though it also did find a trade-off with negative impacts to other species and habitats.)

ECOTOURISM, THEN, has emerged as a potential bridge between outdoor experiences and conservation. The challenge for travelers is that this term typically lacks consistent parameters, regulations and stipulations. Like the word *natural* in the grocery world, *ecotourism* often gets slapped on any flavor of nature-related fun and conventional tourism, according to Stronza and colleagues who published a 2019 review on the matter in *Annual Review of Environment and Resources*.

This conundrum demands a bit more mindfulness and research from eco-conscious travelers grappling with the ethical question: Should I stay, or should I go? But resources abound, once you know where and how to look. The following roundup of destinations and experiences offers some inspiration, lessons learned and ongoing challenges, all in mesmerizing landscapes where tourists, scientists and wild ecosystems are converging at a rapid pace.

Thousands of cenotes pepper the coastal region of the Riviera Maya in southern Mexico.

DIEGO GRANDI/SHUTTERSTOCK

GREG SULLAVAN/ISTOCK VIA GETTY IMAGES

THE GREAT BARRIER REEF

The world's most extensive coral reef system, located in Australia, needs little introduction. But it could use a biological miracle to return to its glory days as a thriving ecosystem.

For context, the Great Barrier Reef (GBR) encompasses an area bigger than the U.K., Switzerland and Holland combined. It's home to some 600 known varieties of hard and soft corals and many more species of fish and marine creatures — though these figures could decline as coral colonies continue to die off.

The GBR itself has been the subject of many dire climate headlines over the past decade, particularly as the abundance of coral dropped by roughly 50 percent over just 30 years, according to a major study of the GBR published in 2020. Two back-to-back mass bleaching events in 2016 and 2017 did exceptional damage — followed by bleaching events in 2020 and 2022. The four occurrences have been attributed to stress due to changing surface temperatures in the ocean.

One consistent challenge for this ecosystem, and all reefs globally, is that oceans absorb roughly 90 percent of the excess heat generated by greenhouse gas emissions in Earth's atmosphere. While this helps buffer and offset the rise of ambient air temperatures around the globe, it can deal deadly blows to reefs. And beyond bleaching events, which have been occurring more frequently, the impact of cyclones, diseases and predatory crown-of-thorns starfish routinely threaten coral. As for direct human impact (besides warming caused by greenhouse gas emissions), degraded water quality and coastal development are significant issues, along with the localized risks of trampling coral, wildlife disturbance or human pollution that can result from snorkeling and other recreation.

Prior to the COVID-19 pandemic, roughly 2 million people visited the Great Barrier Reef Marine Park each year via tourism operations. (While the pandemic nearly slashed that count in half, recent reports show traffic steadily rebounding.) Many of these visitors participate in immersive diving, snorkeling or boating day trips to encounter the marine life and coral. While that activity can certainly increase local degradation, regulated tourism is increasingly contributing to reef conservation, according to researchers with the Australian Institute of Marine Science (AIMS), a government agency handling the longest running

FROM TOP: GBR FOUNDATION; GARY CRANITCH/GBR FOUNDATION

and most comprehensive GBR-monitoring program.

"Marine scientists need all the support they can get from the public in this endeavor," says AIMS coral biologist Cathie Page, when asked how tourists impact the reef.

FOR STARTERS, most visitors to the GBR Marine Park pay upon entry an environmental management fee that supports conservation efforts. At the start of 2020, that program was annually generating over $11 million in Australian dollars (nearly $8 million in USD) of revenue, though the charge has been paused since the pandemic in 2020 to aid tourism recovery. Additionally, many partnerships have started unfolding between researchers, tourism operators and islander locals who visit the reef daily and depend on its health.

In 2020, AIMS launched Boats4Corals as a means of scaling up larval reseeding across reefs. That project, led by Mark Gibbs, teaches tourism operators, recreational boaters and Indigenous islanders how to identify and collect coral spawn, and grow baby corals in floating nurseries and settle them into their local damaged reefs. The Great Barrier Reef Marine Park Authority, which regulates and protects the GBR, also rolled out a Master Reef Guides program in February 2019. The effort instills high-standard tourism practices across the reef and involves a five-day intensive workshop for guides.

GBR tourism generates nearly $2.6 billion (USD) per year for the Australian economy.

On a larger financial scale, the Australian government is currently making its biggest ever move to restore the GBR, through a nearly $300 million (USD) partnership with the Great Barrier Reef Foundation. This Reef Trust Partnership involves more than 300 projects over a six-year period, while incorporating many Aboriginal and Torres Strait Islander peoples plus the booming tourism industry as engines of restoration and sustainability.

Remarkably, despite a decade with significant coral mortality after 2016 and 2017, the GBR's hard corals have shown signs of recovery. Overall, hard coral coverage has increased across the key northern, central and southern sections of the GBR, according to a 2021 condition report by AIMS. But the threat of bleaching events or other climate dangers always looms, while further research will continue to hone prevention and preservation strategies. "We're only starting to scratch the surface in terms of understanding coral reefs and the impacts of human on these ecosystems," says Page.

BEFORE BOOKING tours and excursions, some reef advocates recommend seeking out businesses blazoned with EarthCheck or EcoTourism Australia certifications, which identify outfitters and accommodations that have made efforts toward sustainability. Though, Stronza warns, there are pros and cons to such programs, which often lack thorough assessment of participants and favor larger operations that can afford the fee for certification.

As an alternative, more hands-on option: Travelers can seek out citizen-science experiences that might directly support marine life or reef restoration.

RADIM SCHREIBER/FIREFLYEXPERIENCE.ORG

FIREFLY SPECTACLE

Shortly before dusk, the hazy June air wafting through Great Smoky Mountains National Park runs thick with anticipation.

Near Elkmont Campground, a select group of visitors ventures down a logging road into the forest as a distant river gurgles in the background. The damp soil feels spongy underfoot. Ferns merge with mountain laurel and their showy white blooms in the dim light — then it begins. One blink, spotted like the first star of the night. Then another, prompting a hushed gasp.

At first, the flickers resemble a familiar evening in many an American backyard during firefly season, roughly May through June or July. But this is not just any backyard, nor are these your average fireflies. As more and more join in, a pattern emerges. Two, then 10, and suddenly dozens of fireflies are blinking in rhythm with each other — all males, from the species *Photinus carolinus*. Tufts University biologist and firefly researcher Sara Lewis calls it their “silent love songs.” It’s mating season.

The synchronous *P. carolinus* fireflies typically emit six blinks in succession, pause for several seconds, then repeat. As night descends, hundreds of the pulsing bugs will drift through the foliage in a fluid mass. “It will pass like the wave at ballgames, just a wave of synchrony through the forest,” says Lewis, co-chair of the Firefly Specialist Group of the International Union for the Conservation of Nature (IUCN). “It’s awe-inspiring.”

So inspiring, in fact, that each year approximately 30,000 people enter a lottery for about 1,800 vehicle passes to witness the two-week spectacle in the Smokies.

ESTIMATES SUGGEST more than 1 million people annually now travel to various hotspots for firefly watching. Interest has grown enough to warrant a comprehensive study published in *Conservation Science and Practice* in 2021, evaluating the risk to the insects and best practices for humans. Lewis, who helped lead that research, says the researchers were “gobsmacked” by the activity’s popularity. While firefly watching has a centuries-long history in East Asia, it’s recently grown into a global phenomenon that risks overwhelming management plans at particular locations, the researchers found. Interestingly, it also accounts for just one category within a growing niche of insect-based tourism, dubbed entomotourism.

Tennessee is one of many destinations in at least a dozen countries now spotlighting firefly tourism.

In part, experts attribute the surge in firefly interest over the past decade to advanced camera technology (and digital editing). Better tech has allowed us to photograph these remarkable creatures at night for the first time. And, as images spread online, people want to witness the spectacle for themselves. That combines with a novelty factor, since more and more people live in urban environments that are inhospitable to the bioluminescent beetles. “Places that used to be firefly habitat are now under pavement,” Lewis says.

Out of the 2,200-plus species of fireflies — or “lightning bugs” as they’re known in parts of the U.S. — some are thriving and healthy, while others are struggling.

INSETS, FROM LEFT: ANKO70/SHUTTERSTOCK; CEW/SHUTTERSTOCK

Globally, the primary threats to firefly populations include habitat loss, light pollution and overuse of broad-spectrum insecticides. While tourism does not rank as a top killer, it can pose a significant threat to firefly populations and their habitat, particularly in high-traffic sites that lack regulation.

One major factor that the casual viewer may overlook: Fireflies spend most of their lives as eggs, larvae and pupae bound to the ground or under the soil. These juveniles inhabit wetlands, grasslands and forests, including parks, gardens and lawns in residential areas, typically feeding on snails, worms and other soft prey for several months or even years. All of that precedes a dramatic metamorphosis so they can spend just a matter of days or a few weeks as the flying, glowing adults that mate to continue the cycle, then die shortly after. Adult females also traverse the ground to lay their eggs. Human ground traffic, development and insecticides can wipe out countless fireflies before any human sees a blink.

THE LIST OF BEST practices at a firefly-viewing site includes staying on the trail and avoiding the use of flashlights and other bright lights. Even the screen of a cellphone or a camera flash has been shown to disrupt courtship behaviors. Travelers also can consider seeking out less popular sites. The Xerces Society for Invertebrate Conservation manages a map online showing recommended firefly tourism locations. Distributing the love will allow the bugs in the high-traffic areas to recover and thrive. "It's a big thing to have 10,000 people descend on your home in a few-week span," Lewis says.

OTHER EXPERIENCES

GLACIER TOURISM

Evidence across decades has documented the shrinking of famous glaciers in our warming climate. This reality makes glaciers a prime candidate for "last chance tourism," where the pending disappearance of a structure or species drives intrigue and traffic. The irony, of course, is that traveling to such novelties often generates greenhouse gases or inflicts direct harms that accelerate their disappearance. One potential benefit to glaciers: You can admire them from a distance, at least for now, without any direct contact.

AMAZON EXPLORATION

Stronza recommends two destinations in South America as exemplary versions of sustainable, beneficial ecotourism: The Kapawi Ecolodge Project in Ecuador and Posada Amazonas in Peru. Kapawi, which is fully owned by the Achuar Indigenous Nation, offers multiday rainforest hikes, family-style meals and tea ceremonies, plus lodging in traditional Achuar bungalows. In southeast Peru, Posada Amazonas immerses travelers in the Indigenous culture and natural wonders of the Tambopata jungle, with 75 percent of profits going to the Ese Eja Native community of Infierno.

CENOTES OF MEXICO'S YUCATÁN PENINSULA

For millennia, Mexico's freshwater cenotes sustained the lives and rituals of ancient Maya civilizations long before Spanish colonization.

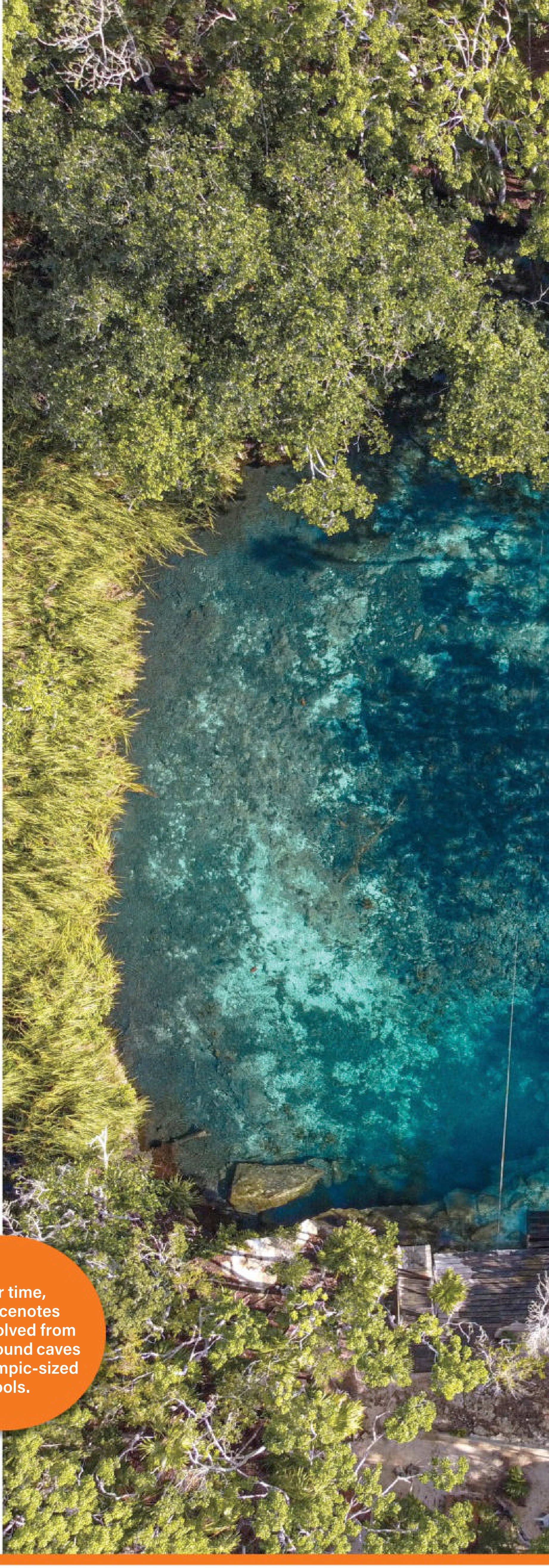
Today, on a larger scale, they remain a vital resource and alluring feature of the limestone block forming the Yucatán Peninsula. "Through geological time, the flow of the water has created these voids that eventually collapse to form the cenotes," says hydrogeologist Emiliano Monroy-Ríos, who specializes in cenotes.

Thousands of these sinkholes remain barely touched, with new ones appearing and existing ones expanding regularly. Many of these cenotes are part of the world's largest underwater cave system, Sac Actun, often referred to as an underground river and archaeological frontier. As recently as 2015, a previously unknown cenote was discovered underneath the famous Maya temple pyramid at Chichén Itzá. Then there are the day resort or nature park attractions, such as Gran Cenote, or Cenote X'Canche adjacent to the Ek Balam Archaeological Site. These massive cenotes might feature diving platforms, rope swings, and guided tours or floating trips to draw wide-eyed adventurers.

In Monroy-Ríos' view, sharing a limited number of these destinations with tourists poses relatively minor risk to the aquifer ecosystems — though he prefers sites that minimize modification to the natural features, as well as tour groups that limit capacity and educate visitors about the importance of the waterway.

MUCH BIGGER questions remain unanswered about the impact of adding a nearly-1,000-mile railway that would send both passenger and cargo trains across the fragile topography. Such is the scale of Tren Maya, which President López Obrador began rolling out in 2020, with a promised completion date of 2024.

Monroy-Ríos describes Tren Maya as "a monster project" that has been rushed and poses significant risks to the environment. The government plan, with costs ballooning to over $20 billion as of late 2022, has evolved from a campaign promise to actual construction in fragmented phases, without the completion of various impact assessments and environmental reviews. In 2022, more than 300 researchers and academics signed a public letter asking López Obrador to cancel the project, which has barreled ahead despite public outcry and legal challenges. "Collapses happen all the time," Monroy-Ríos says of the porous limestone across the region. "A big project like this can induce some of these collapses."

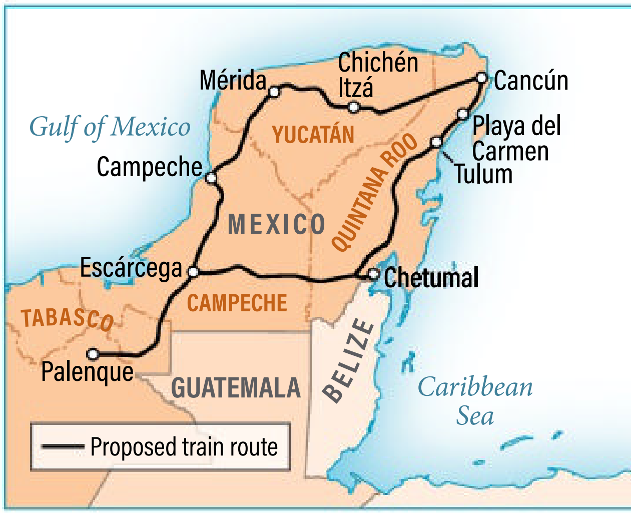


Over time, some cenotes have evolved from underground caves into Olympic-sized pools.

Beyond engineering, safety and environmental concerns, archaeologists are raising flags. That's because, remarkably, many of the region's cave systems were dry and accessible to humans and animals roughly 10,000 years ago, when the water table was much lower. Over the past few decades, cave-diving specialists have begun exploring the system, with an eye toward archaeological artifacts, as well as the geology and hydrology. In 2014, researchers confirmed that a human skeleton found in a cenote in 2007 is likely more than 12,000 years old, revising history books on the timetables of human migration to the region. Other discoveries have included the bones of prehistoric giant sloths that likely spent time in the caves — perhaps alongside humans — around the last Ice Age.

IN PART, archaeologists worry the train's path could disturb hundreds of historical sites and compromise important dive zones, leaving countless artifacts lost to science.

Beyond that, Monroy-Ríos notes that overdevelopment of the area already puts a burden on the aquifer supplying clean water. He fears that any contamination of the waterway below the surface would be nearly impossible to contain: "[An] accident could be irreversible for the groundwater in general and the ecosystems that live down there."



The 950-mile path of the railway: good for commerce, bad for preservation.

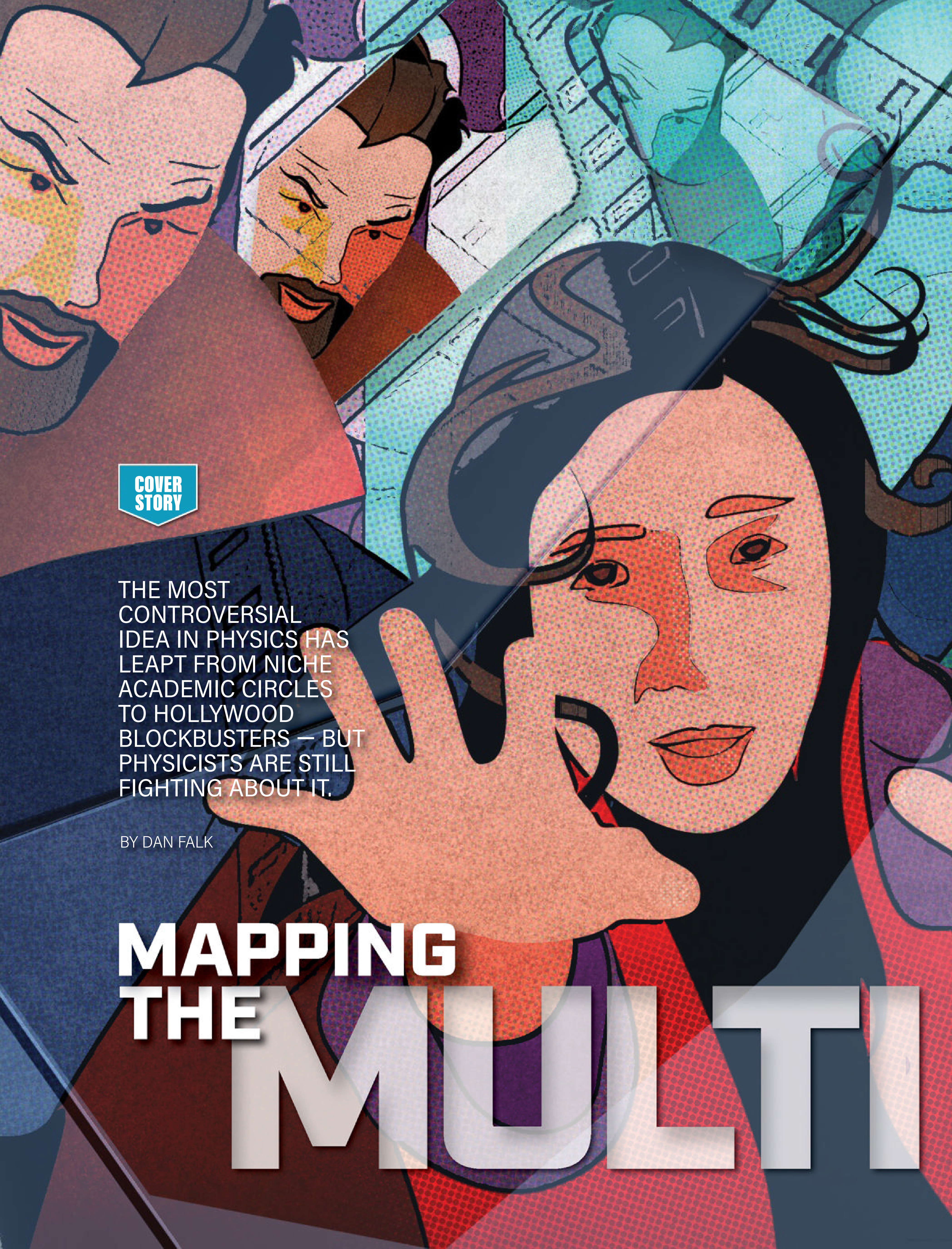
Monroy-Ríos adds that he is not opposed to a train in any shape or form. Rather, he believes the project requires more rigorous engineering assessments. Some judges have agreed, creating legal blocks to López Obrador's incremental work.

As to the tourism at current cenote destinations, Monroy-Ríos says it poses some opportunity for support and protections. "The more exposure and the more information we have, it's just a better way to conservation in general," he says. And yet, more tourism inevitably means more development, which he acknowledges is a double-edged sword for the region's future.

***Tree Meinch** is features editor at* Discover. *Follow @timeinch on Twitter.*

TRAVEL TIPS
Scan the code with your phone for the "secret sauce" in eco-minded tourism.

LEFT: NEHUENPG/SHUTTERSTOCK. TOP: JOANA VILLAR/SHUTTERSTOCK. MAP: ROEN KELLY/DISCOVER

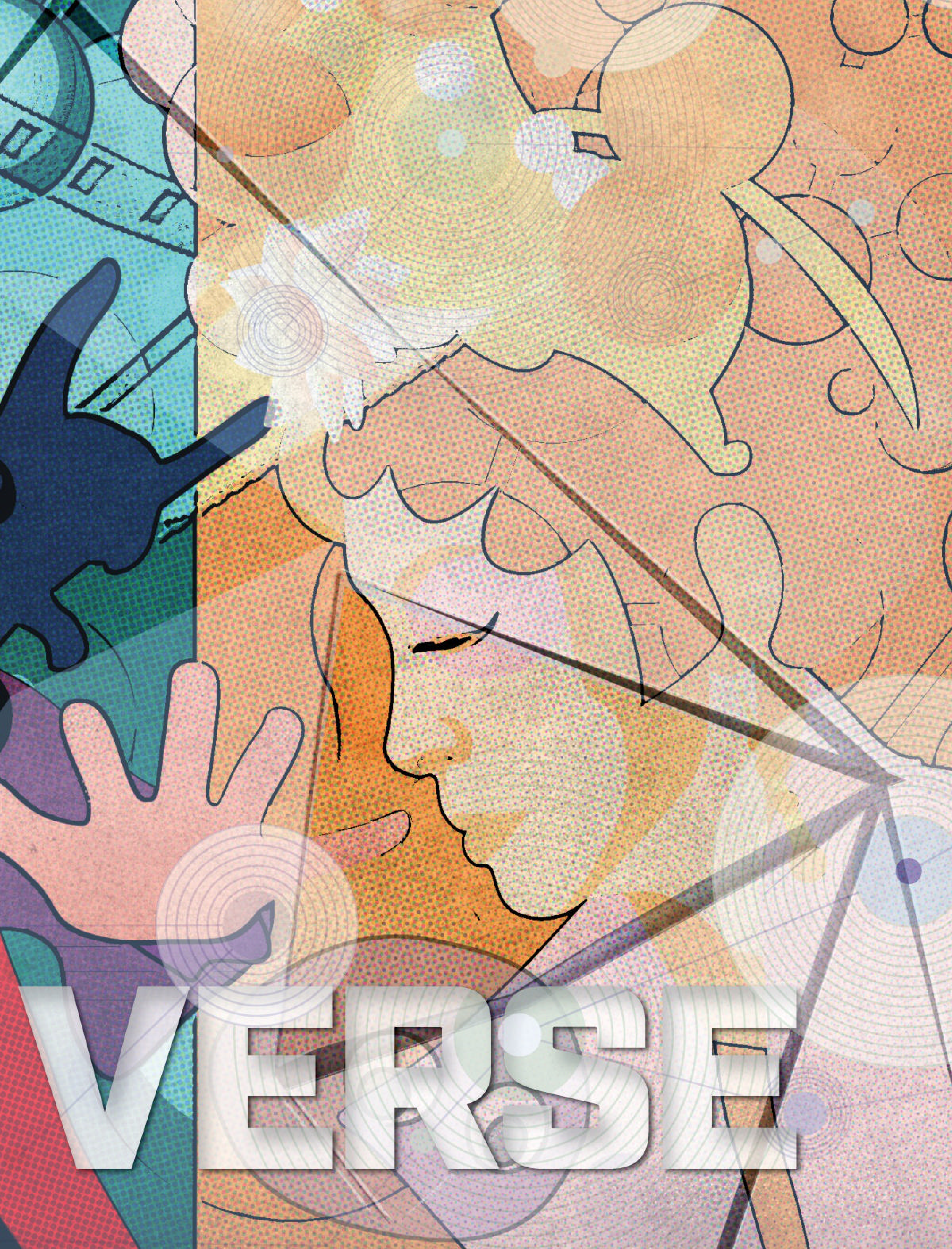


COVER STORY

THE MOST CONTROVERSIAL IDEA IN PHYSICS HAS LEAPT FROM NICHE ACADEMIC CIRCLES TO HOLLYWOOD BLOCKBUSTERS — BUT PHYSICISTS ARE STILL FIGHTING ABOUT IT.

BY DAN FALK

MAPPING THE MULTI


VERSE

IN THE *STAR TREK* episode “Mirror, Mirror,” which first aired in 1967, Captain Kirk and crew must escape from a parallel universe before being discovered by their nefarious counterparts.

IF YOU LIVE ON THIS PLANET — AND YOU’RE OF A CERTAIN AGE — THERE’S A DECENT CHANCE YOU’VE SEEN THE CLASSIC *STAR TREK* EPISODE “MIRROR, MIRROR,” IN WHICH CAPTAIN KIRK AND SEVERAL MEMBERS OF THE *ENTERPRISE* FIND THEMSELVES IN WHAT APPEARS TO BE A PARALLEL UNIVERSE.

The trouble starts when they attempt to beam up from a planet during an ion storm. Something goes wrong. They appear aboard the *Enterprise*, but things are askew: Crew members greet the captain with Nazi-style salutes, and First Officer Spock sports a goatee. Observing these small but significant differences, Kirk muses that the crew has materialized in “a parallel universe coexisting with ours on another dimensional plane.”

These days, one parallel universe is hardly enough for science fiction. Instead, it seems the entire multiverse is having its Hollywood moment. Films like *Doctor Strange in the Multiverse of Madness* and *Everything Everywhere All at Once* entice the viewer with multiple versions of various characters and a dizzying array of alternate realities. Though they’re not particularly heavy on the physics, these films are definitely latching onto something. The idea of the multiverse — the provocative notion that our universe is just one of many — has fully cemented itself in mainstream pop culture. (Or, at least, in the current phase of the Marvel Cinematic Universe.) Its appeal as a storytelling device is obvious. Just as time travel allowed Marty McFly to experience different timelines in the *Back to the Future* series, multiverse tales allow characters to explore a multitude of worlds with varying degrees of similarity to our own, as well as altered versions of themselves.

While Hollywood can’t seem to get enough of the multiverse, it remains deeply controversial among scientists. Ask a prominent physicist whether they believe in a multitude of universes beyond our own, and you’ll get either a resounding yes or a vehement no, depending on whom you encounter. Advocates on the two sides show no mercy toward each other in their books, on their blogs, and, of course, on Twitter. But physicists didn’t pull the idea out of thin air — rather, several distinct lines of reasoning seem to point to the multiverse’s existence, bolstering the idea’s merit. Sabine Hossenfelder, a theoretical physicist at the Frankfurt Institute for Advanced Studies, has called the multiverse “the most controversial idea in physics.”

The debate over the existence of unseen universes may seem rather pie-in-the-sky. After all, how could worlds that we can never visit — or even detect — possibly affect anyone’s life? But the stakes are higher than they appear: Critics caution that legitimizing the multiverse could make it harder for the public to distinguish science from speculation, making it more difficult to keep pseudoscience at bay. (If scientists can’t agree about how many universes exist, how can the public be sure there’s a consensus on the reality of climate change, or the efficacy of vaccines?) Writing in the journal *Nature* in 2014, physicists George Ellis and Joe Silk describe the debate over the multiverse as a “battle for the heart and soul of physics.”

Philosophers have pondered a multiplicity of worlds at least since the ancient Greeks. But it was only in the 20th century that astronomers and physicists began to talk about multiple universes in the terms we use today.

In the 1920s, astronomers found that

PREVIOUS SPREAD: KELLIE JAEGER/DISCOVER. THIS PAGE, TOP FROM LEFT: PARAMOUNT/COURTESY EVERETT COLLECTION (2); CBS PHOTO ARCHIVE/CBS VIA GETTY IMAGES. FILM STRIP: SIMBERT BRAUSE/SHUTTERSTOCK

distant galaxies are moving away from each other, implying that the universe itself is expanding. If you ran a recording of the history of our cosmos backwards, the galaxies would be seen rushing toward one another. The inescapable conclusion was that, in the remote past, the universe was much smaller, denser, and hotter. This discovery gave rise to the Big Bang model of cosmology, which describes how the universe evolved over the past 13.8 billion years from an ultra-dense blazing fireball to the enormous and vast expanse we know today.

The first pathway to suspecting there might be a multiverse emerged when scientists found problems with this original Big Bang model. The universe today is highly structured. Matter has clumped together to form stars, planets, and galaxies, while the space between these objects is nearly empty. And yet under the Big Bang model, the very early universe is believed to have been incredibly homogeneous, with every part just about as hot and dense as every other part, like a cup of hot chocolate that's been thoroughly stirred.

So how did today's clumpy, structured universe come about? In the 1970s and '80s, a handful of physicists, led by Alan Guth, Andrei Linde and Alexei Starobinsky, put forward a modified version of the Big Bang, known as inflation. In the inflation model, some tiny bit of space-time underwent a stupendous (if brief) growth spurt, lasting no more than a trillionth of a trillionth of a second. This exponential expansion enlarged miniscule variations in the distribution of matter throughout the universe. Over time, those variations grew to be the galaxies and clusters of galaxies that now pepper the cosmos, containing within them countless stars and planets.

But if inflation could blow up one bit of space-time, why not many bits of space-time? Why shouldn't inflation be happening continuously, creating new universes all the time? There didn't seem to be any way to constrain inflation so that it yielded just one universe — and so the notion of "eternal inflation" was born, and the idea of multiple universes with it. In this view, little pocket universes — Stephen Hawking preferred the phrase *baby universes* — are continuously popping up, with the tally of new universes endlessly increasing. (In the context of "Mirror, Mirror," we might imagine a universe where Spock has a full beard or mohawk, alongside an infinite number of other scenarios.)

Some physicists welcomed this multiplicity of universes. In his lecture slides, Linde, one of eternal inflation's greatest champions, has depicted these universes as little colored spheres, bubbling up and creating new bubbles as they evolve, like a frothy pot of boiling water. He is on record as saying he'd bet his life that the multiverse is real.

Others are more cautious. Andreas Albrecht, a theoretical physicist at the University of California, Davis, who alongside Princeton University theoretical physicist Paul Steinhardt helped shape inflation into its modern form, finds eternal inflation troubling. That trouble stems from the idea of infinity itself.

To be sure, infinity is no problem for mathematicians scribbling equations on blackboards. But physicists strive to describe the real world, where one doesn't encounter an infinite number of anything, let alone universes. "At the end of the day, my physics instincts

THE MULTIPLE MULTIVERSES

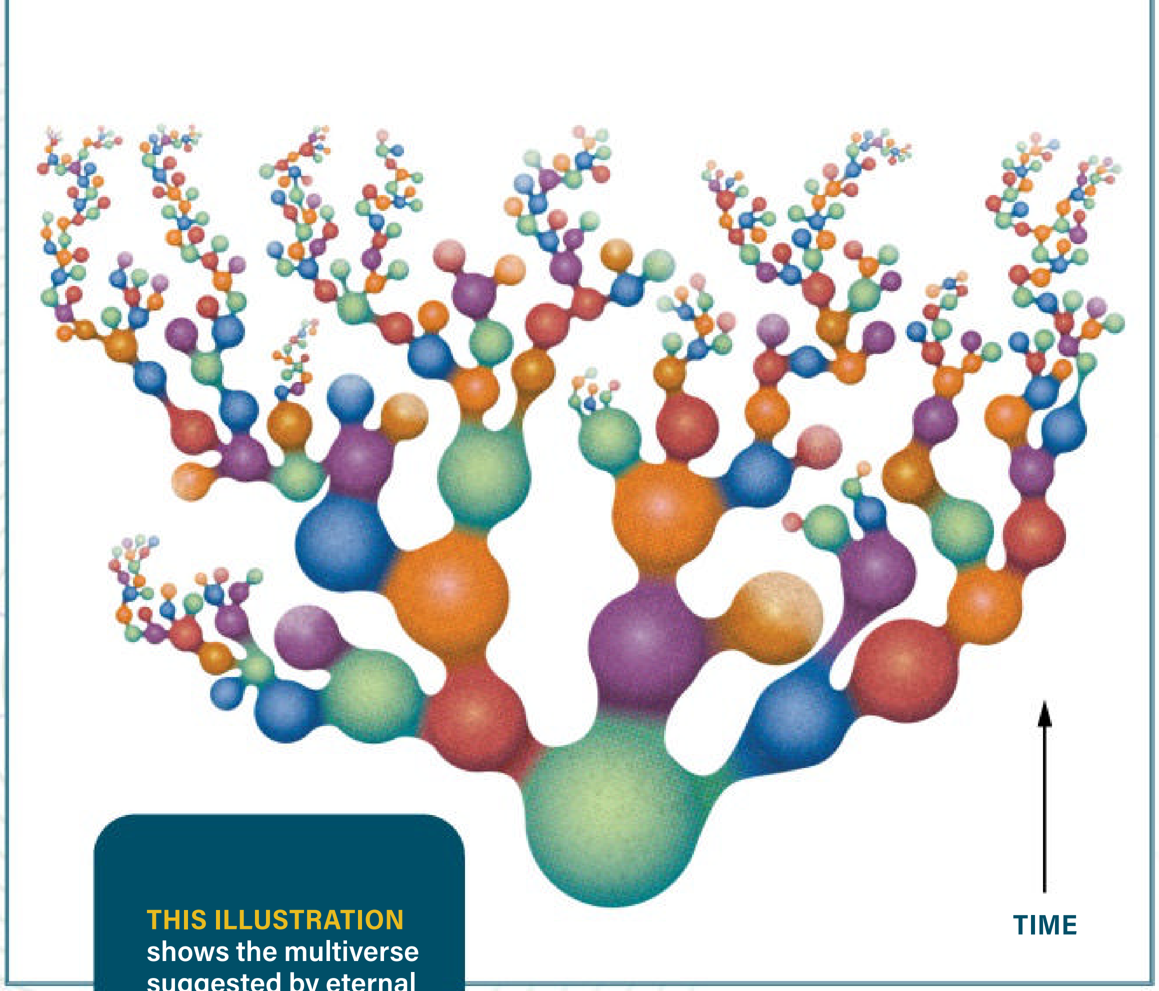
There isn't just one theory that suggests we live in a multiverse. In fact, physicists have found that several different ideas in particle physics and cosmology appear to point to the existence of universes beyond our own.

ETERNAL INFLATION: This multiverse model presents a world where little "pocket universes" are continuously popping into existence. It stems from the idea of cosmological inflation, which posits that the universe went through a massive growth spurt in the first moments of the Big Bang. These pocket universes grew just as ours did, and might now contain stars, planets and galaxies like ours.

STRING THEORY: In this theory, our universe is described as though made up of tiny, vibrating strings that are too small to detect. The equations of string theory have billions upon billions of solutions; some physicists believe this leads to a "landscape" of different universes. The idea may be closely related to eternal inflation.

MANY WORLDS: An attempt to explain a key aspect of quantum mechanics, the many worlds theory says that the universe splits each time a quantum measurement is made. This leads to an ever-growing array of universes within a branching multiverse. The model suggests that this multiverse contains multiple copies of you, as well.

THIS PAGE, TOP: MATTHIEUCLOUIS/DREAMSTIME. GEOMETRIC BACKGROUND THROUGHOUT: AMTITUS/DIGITALVISION VECTORS VIA GETTY IMAGES



THIS ILLUSTRATION shows the multiverse suggested by eternal inflation, where new universes are constantly forming.

pull me away from eternal inflation," Albrecht says.

Steinhardt points to another shortcoming of eternal inflation: The theory says nothing about what any one particular universe will be like. "The problem is, now you have a theory which makes no predictions," he says. "For any property that you can imagine, the opposite of that property also occurs, an infinite number of times." Hossenfelder is equally skeptical: "In eternal inflation, they say they have all these universes popping up. And I'm like, well, where are they popping? Of course, no one sees anything popping; it's just there in the mathematics."

Through the 1980s and early '90s, even with inflation slowly solidifying its status as the go-to model of the early universe, the idea of eternal inflation remained little more than a sideshow. Most physicists didn't worry too much about the (alleged) extra universes. Out of sight, out of mind, as it were.

However, another idea from the frontiers of physics was brewing at around the same time — and it seemed to lend support to the many-universes idea. This new approach came from string theory, the notion that the universe is made up of tiny, vibrating strings, far smaller than anything we could see through our best microscopes, or even detect with our most powerful particle accelerators.

String theory's equations allow for a multitude of solutions, each corresponding, physicists have suggested, to a distinct universe. And so, like eternal inflation, string theory appears to allow for a staggeringly vast array of universes. Stanford University physicist Leonard Susskind described the resulting picture as a "landscape" of universes, seemingly echoing the multiverse given by eternal inflation. In fact, many physicists believe the two ideas are intimately related. "You can't separate them," says Sean Carroll, a theoretical physicist at Johns Hopkins University. "One is saying that different regions, where there are different local laws of physics, can possibly exist; that's what the string theory landscape is saying. Inflation is saying, 'And they become real.' "

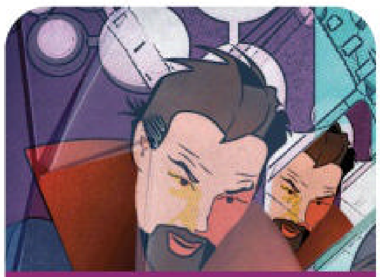
The multiverse controversy is rooted in the notion of testability. If we can't interact with these other universes, or detect them in any way, some experts insist that relegates them to mere philosophical speculation. But multiverse proponents see it differently: There may be very good reasons to believe in the multiverse, they argue, even if we cannot poke at it or glimpse its many universes.

Albrecht, like many physicists, was never comfortable with the version of the multiverse suggested by eternal inflation or string theory. Still, he found himself drawn to another kind of multiverse — the one offered by the "many worlds" interpretation of quantum mechanics.

First, a Quantum 101 refresher: Quantum mechanics rests on the idea of a wave function, a kind of mathematical recipe for predicting where a particle will be, or how it will be moving, at some particular moment. Wave functions evolve over time; that evolution is governed by the Schrödinger equation, roughly analogous to Newton's equation F = ma (force equals mass times acceleration). Where Newton's physics determines the path of a thrown baseball, Schrödinger's equation predicts the future state of a quantum system. The catch is that we cannot know what state a quantum system is in until we measure it. Prior to measurement, it can even be in a superposition of states; that is, it's in many states all at once. Sound familiar?

To demonstrate the principle, consider an electron. According to quantum mechanics, an electron can spin in two different ways ("up" and "down," in physics terms). Before you look at the electron, the theory says its spin is indeterminate; it can be in both states, spin-up and spin-down. But when you actually measure the electron's spin, the wave function "collapses," and the superposition goes away; you're left with one spin or the other. This view is called the Copenhagen interpretation of quantum mechanics, after the city where its first proponents, Niels Bohr and Werner Heisenberg, worked.

Some, like Erwin Schrödinger, worried about the possibility of quantum effects scaling up and impacting the



STRING THEORY'S EQUATIONS ALLOW FOR A MULTITUDE OF SOLUTIONS, EACH CORRESPONDING, PHYSICISTS HAVE SUGGESTED, TO A DISTINCT UNIVERSE.

KELLIE JAEGER/DISCOVER

IT'S A WONDERFUL LIFE

SLIDING DOORS

DOCTOR STRANGE

THE MULTIVERSE ON SCREEN

As the titular Doctor Strange, Benedict Cumberbatch flits between universes with ease. Mild-mannered laundromat owner Evelyn Wang (Michelle Yeoh) battles her own demons from various branches of the multiverse. Tom Holland's Peter Parker takes a spin with alternate versions of the character from prior movies.

From *Doctor Strange in the Multiverse of Madness* and *Spider-Man: No Way Home* to *Everything Everywhere All at Once*, alternate universes are plentiful in movies today. But writers and filmmakers have been exploring the topic for nearly a century. On screen, some of these stories allude to physics; often, the parallel universes are merely imagined, playing out only in a character's head. But these tales all capitalize on what the multiverse offers — endless chances to imagine what could (or should) have happened if things went differently.

Here is just a sampling of the many films that have toyed with the idea of multiple universes, and are well worth your time.

IT'S A WONDERFUL LIFE (1946): In this Christmastime classic, George Bailey (James Stewart), contemplating suicide, tells his guardian angel, Clarence Odbody (Henry Travers), that he wishes he'd never been born. But Odbody shows Bailey an alternative universe in which he had indeed never lived — and it's much worse. In the end (75-year-old spoiler alert), Bailey asks for his original life back.

RUN LOLA RUN and ***SLIDING DOORS*** (both 1998): In both of these films, the central character experiences multiple timelines depending on how a specific moment unfolds. In *Run Lola Run*, it all hinges on what happens when Lola (Franka Potente) runs down the stairs of her apartment. In *Sliding Doors*, the timelines diverge depending on whether Helen Quilley (Gwyneth Paltrow) manages to board a London Underground train before the doors close.

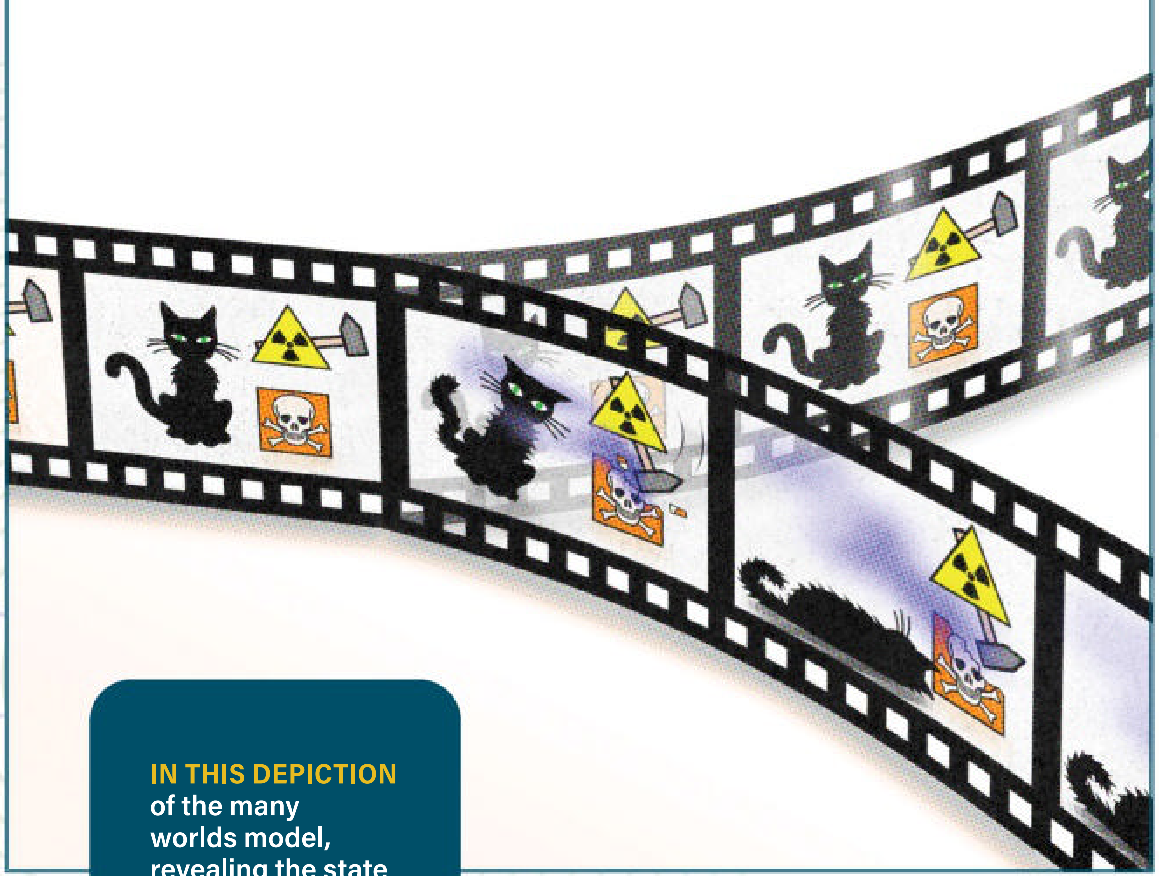
THE ONE (2001): The multiverse figures prominently in this Jet Li action film, in which a rogue agent travels to parallel universes in order to kill other versions of himself.

COHERENCE (2013): A reunion for a group of friends goes awry when a passing comet splits reality in two. Their only hope for survival is to hunt down their multiverse doppelgängers.

DOCTOR STRANGE (2016): The film presents Doctor Strange's origin story — and at least pays lip service to modern physics. At one point The Ancient One (Tilda Swinton) says to Strange (Benedict Cumberbatch): "This universe is only one of an infinite number. Worlds without end. […] Who are you in this vast multiverse, Mr. Strange?"

SPIDER-MAN: INTO THE SPIDER-VERSE (2018): This multi-dimensional take on the web-spinner features multiple Spideys from multiple Earths — including a version of the superhero as a talking cartoon pig. In 2019, it won the Academy Award for Best Animated Feature. — D.F.

FROM LEFT: EVERETT COLLECTION; © MIRAMAX/COURTESY EVERETT COLLECTION; © WALT DISNEY STUDIOS MOTION PICTURES/EVERETT COLLECTION



IN THIS DEPICTION of the many worlds model, revealing the state of Schrödinger's cat splits the universe into distinct branches.

everyday world — his famous alive-and-dead cat is the quintessential example. The standard view was that, if you could somehow maintain a cat in a superposition of states (current thinking suggests this would be astoundingly difficult), the wave function of the cat would collapse when observed, just as with an electron.

Some physicists find the Copenhagen interpretation unsatisfying. Why do measurements cause wave functions to collapse, and what qualifies as a measurement in the first place? Maybe, a few thinkers have suggested, the wave function doesn't collapse. Ever. Instead, when we make a measurement, the universe divides, or branches, creating a brand-new universe for each possible outcome. (Some experts caution against this phrasing as being overly simplistic, but it will do for our purposes.) When we look at that electron, the universe splits in two, with one universe containing a spin-up electron and one containing a spin-down electron. Schrödinger's cat is similarly tamed: In one universe, the cat lives; in another, it dies. These universes also contain unique copies of you — or, unique copies of universe-hopping Evelyn Wang, in the case of *Everything Everywhere All at Once*.

This many worlds view of quantum mechanics was first set out by physicist Hugh Everett in the 1950s, and has slowly gained followers in the decades since. Albrecht is one of them; he sees the idea as elegant. For him, the Copenhagen notion, with its mysterious appeal to ill-defined "measurements," is unwieldy and awkward. Plus, quantum mechanics works; it's much more than just equations on chalkboards, with actual technology like lasers, semiconductors, atomic clocks and MRI scanners to show for it. Carroll is also an ardent advocate for Everett's model, arguing the case in his 2019 book *Something Deeply Hidden*, in which he calls the theory's array of unseen universes "indisputably real."

Max Tegmark, a physicist at MIT, expounded on the many worlds model in his 2014 book *Our Mathematical Universe*. Tegmark says he often thinks about the other copies of himself in those other worlds: "I feel a strong kinship with parallel Maxes, even though I never get to meet them," he writes. "They share my values, my feelings, my memories — they're closer to me than brothers."

For Hossenfelder, however, those parallel Maxes are mere fiction, along with most conjecture about the multiverse. The problem, as she sees it, is that we take the equations too seriously, a position she details in her 2018 book, *Lost in Math*. Hossenfelder takes the view of an instrumentalist, a philosophical stance that says we should take a theory seriously only if it leads to verifiable, measurable predictions. In this view, Everett's theory offers a particular mathematical approach to quantum mechanics, but says nothing about what's really out there. In Hossenfelder's eyes, Albrecht and Carroll have made the mistake of thinking that the math behind the theory is real.

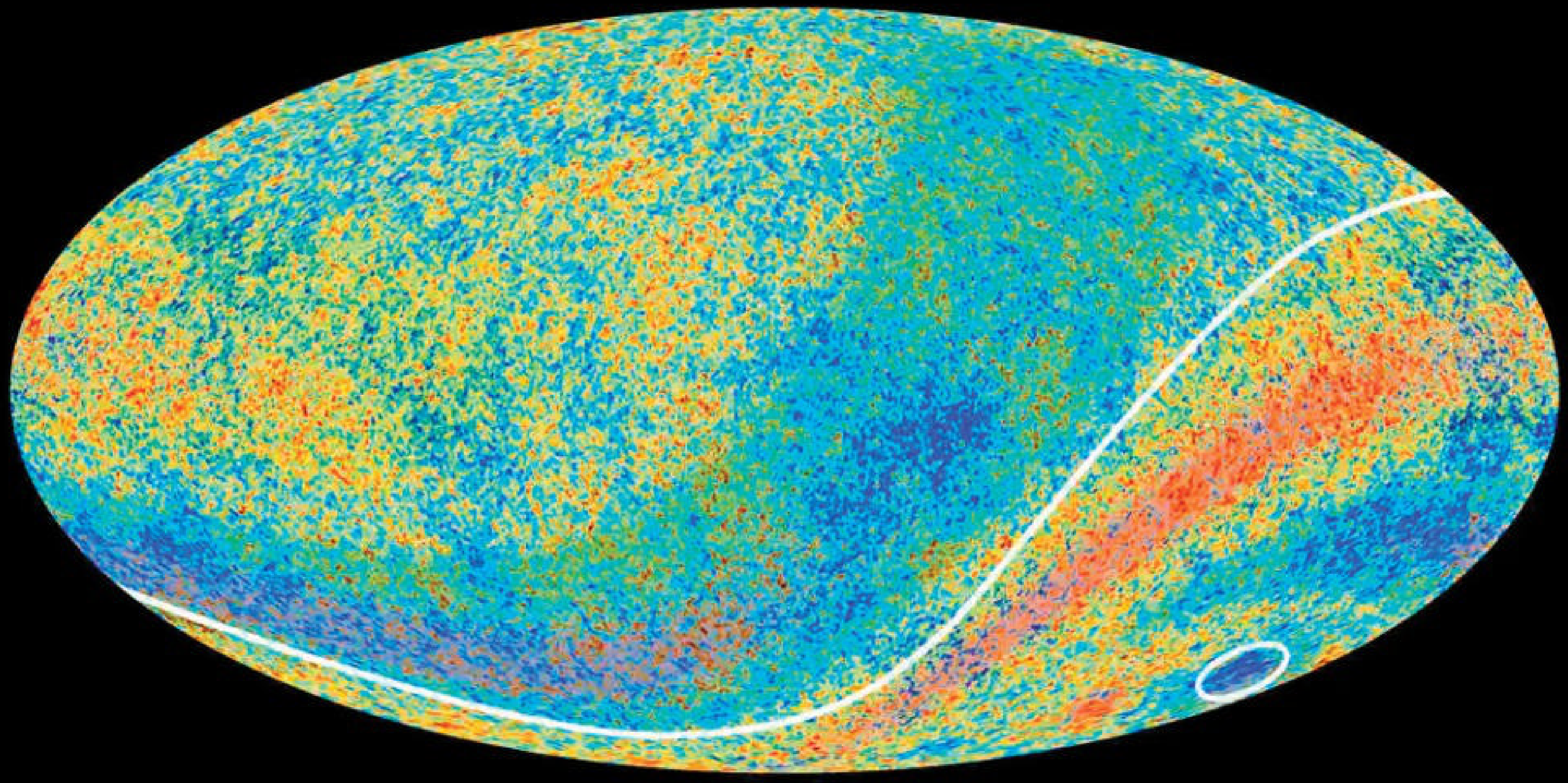
Carroll vehemently disagrees. He argues — channeling Galileo — that mathematics is the language we use to describe our physical theories; it is not some extra, added ingredient. "No one looks at F = ma and goes, 'Oh, that's mathematics, I don't trust it, I'm going to stick to physics,' " Carroll says. For him, Newton's equation is obviously physics, and so is Schrödinger's. If Schrödinger's equation predicts the existence of many worlds, so be it. If we take Newton seriously, we should take Schrödinger seriously, too.

Most physicists see Everett's many worlds as fundamentally different from those given by eternal inflation or by the landscape version of string theory. (Though a few theorists, including Susskind and Tegmark, have speculated that they may be connected.) Even so, the fact that several pathways seem to point to a multiverse suggests that the idea is worthy of such scrutiny. "Whether there's a multiverse or not does not hinge on any one theory being right or wrong," says veteran science writer Tom Siegfried, who examined the history of the multiverse idea in his 2019 book *The Number of the Heavens*. "There are different possible ways there could be a multiverse, and we don't know if any of them are correct. [...] But we have reasons to take some of these ideas seriously."

The way Hossenfelder sees it, having a basket of speculative theories is no better than having just one. In every case, we're asked to believe in the existence of universes that we can never see or study. "I'm not saying it's wrong," she says. "I'm just saying it's no longer science."

ONCE, WE IMAGINED THE EARTH AND THE SUN WERE UNIQUE; NOW WE KNOW THAT EVERY STAR IS A SUN, AND THAT MANY HAVE PLANETS ORBITING AROUND THEM.

CHRISTIAN SCHIRM/WIKIMEDIA COMMONS



THIS IMAGE shows the relic radiation left by the Big Bang. The pattern has helped scientists understand the evolution of our universe.

ESA/PLANCK COLLABORATION

The controversy may sound like harmless infighting among a small group of physicists. But in their 2014 *Nature* essay, Ellis and Silk argued that if physicists aren't careful in distinguishing speculative theories from established fact, the public could be led astray. Giving credit to such speculation could "open the door for pseudoscientists to claim that their ideas meet similar requirements."

Or, as Columbia University physicist Peter Woit wrote on his blog, those who support the multiverse idea risk "turn[ing] fundamental physics into pseudo-science." For Nobel laureate physicist David Gross, invoking unseen universes to explain the properties of the one we actually see is a bit like invoking God. He once said that it "smells of religion and intelligent design."

As scientists struggle to choose between competing explanations for what they observe, a ghost often appears in the battlements — not the ghost of King Hamlet, in this case, but that of William of Ockham. The 14th-century English churchman and philosopher is best known for Ockham's Razor, which suggests that simple explanations are better than more complicated ones. Taken at face value, Ockham's approach might appear to argue against the multiverse on the grounds that it carries excessive baggage (all of those unseen universes) when we just experience a single universe. For many physicists, the argument ends there. If simpler is better, why not stick with the universe we actually see?

Except, explains Siegfried, Ockham did not merely say that simpler is better. Rather, in devising an explanation, it's desirable to use the fewest principles, even if they lead to complex results, Ockham argued. (It's no knock against, say, astrophysics, that it predicts billions of planets orbiting billions of stars.) Not only that, Ockham was actually pro-multiverse. "Ockham himself was the biggest advocate for the multiverse," Siegfried says. "He argued vigorously against all of Aristotle's objections to having more than one universe. So it's kind of ironic that people use Ockham's Razor to argue against the multiverse."

In the movie *Spider-Man: No Way Home*, there's a playful scene in which today's web-spinner, played by Tom Holland, meets parallel-universe versions of himself from earlier films, played by actors Andrew Garfield and Tobey Maguire. This is, to be sure, straight-up fiction. We have no chance of ever actually seeing the universes described by eternal inflation, string theory, or the many worlds version of quantum mechanics. That also nixes the odds of ever encountering our other selves. The odds are similarly low that the debate over the multiverse will end soon.

But history, according to Siegfried, suggests which way the wind is blowing: At one time, the only galaxy we knew of was the Milky Way; now we know that billions of other galaxies are scattered throughout the universe. Could a more expansive view of the universe itself be the next breakthrough? As Siegfried puts it: "Every time in the past that we've thought, 'We've got it; this is what the whole universe is' — the people who've said, 'Maybe there's more than one of those' have always turned out to be right." D

***Dan Falk** (@danfalk) is a science journalist in Toronto. His books include* The Science of Shakespeare *and* In Search of Time.

A TASTE FOR WASTE

WITH CHALLENGES TO THE GLOBAL FOOD SUPPLY CHAIN MOUNTING, THE BLACK SOLDIER FLY'S INSATIABLE APPETITE AND NUTRITIOUS POTENTIAL HAS SCIENTISTS BUZZING.

BY JOHN RIHA

Like any superhero, the black soldier fly is suitably attired. It has a nearly indestructible ebony exoskeleton, wings that fold to form a shimmering, iridescent cape, and an anvil-shaped helmet that sports bulbous eyes and an impressive set of antennae. Despite its formidable name and appearance, however, the 3/4-inch-long fly has a mild, Clark Kent-esque demeanor. It doesn't bite, isn't a disease vector and doesn't chow down on garden veggies. And it won't buzz about your backyard barbecues, because it's not even a good flier.

But *Hermetia illucens* does have a superpower. What it does — and does well enough to qualify it as a potential planet-savior — is digest stuff. The implications for global health and food security are huge.

THOUGH THEY ARE positively ravenous while young, fully grown black soldier flies have no need for digestive systems (or even mouths) because they spend all their time mating.

WHILE THE species is native to Central and South America, *H. illucens* can now be found in tropical and temperate climates around the world.

"It'll eat just about anything organic," says Jeffery Tomberlin, a professor in the Department of Entomology at Texas A&M University. Tomberlin, who has studied black soldier flies (BSF) for more than a quarter-century, doesn't hold back when it comes to his admiration for *H. illucens*. "It's like Prometheus bringing fire to humanity," he says.

It might seem a stretch to assign mythic significance to an insect's digestive system, but the black soldier fly's ability to consume garbage, waste products, carrion and even excrement is nothing short of heroic. Other saprophytes — certain housefly maggots, fungi and soil bacteria — perform the same essential task of converting dead stuff into organic building blocks such as amino acids and glucose, but few organisms have the voracious appetite and digestive efficiency of this fly.

During their two-week feeding period, the larvae do nothing but eat, growing to hundreds of times their original size and becoming a squirming mass of chubby grubs full of proteins and fats. What comes out the rear ends of the larvae is just as remarkable as what goes in their mouths. Thanks to unique digestive enzymes, their poop is nutrient-rich and virtually free of pathogens — clean enough that the coffee-grounds-like excrement, called frass, can be used as a plant fertilizer without extensive processing.

And, speaking of eating, black soldier fly larvae themselves are edible. What's more, studies suggest the chitin of *H. illucens* (basically its crunchy exoskeleton) may be an effective immune booster. Whether alive or dried and ground into meal, the larvae can be used as a nutritious supplement in the diets of livestock — and they may be arriving in superhero fashion in the nick of time.

WORLD FOOD NEEDS can be characterized as an increasing demand for protein sources. According to the World Resources Institute, demand for ruminant meat — from cattle, sheep and goats — will grow 88 percent by 2050.

But ruminants are problematic; they currently use two-thirds of global agricultural land (and produce about half of agriculture's greenhouse gas emissions such as methane). Without a dramatic improvement in farm efficiency, the land needed to meet new demand could wipe out most of the planet's forests and species, all the while releasing enough greenhouse gases to raise global temperatures a disastrous 2 degrees Celsius.

That's only one aspect of the protein problem. Demand for meat means an ever-increasing need for livestock feed that's typically made with protein from soybeans and fishmeal (dried and pulverized fish). For farmers, whose feed bills already account for around half of operational costs, feed prices are escalating. According to World Bank commodity price data, the price of fishmeal rose more than 25 percent between 2010 and 2020.

"Animal feed is the biggest expense for livestock," says Matan Shelomi, an associate professor of entomology at National Taiwan University. "The fishmeal used in much feed is both expensive and taxing on Earth's fisheries."

While the world population has doubled over the past 50 years, the

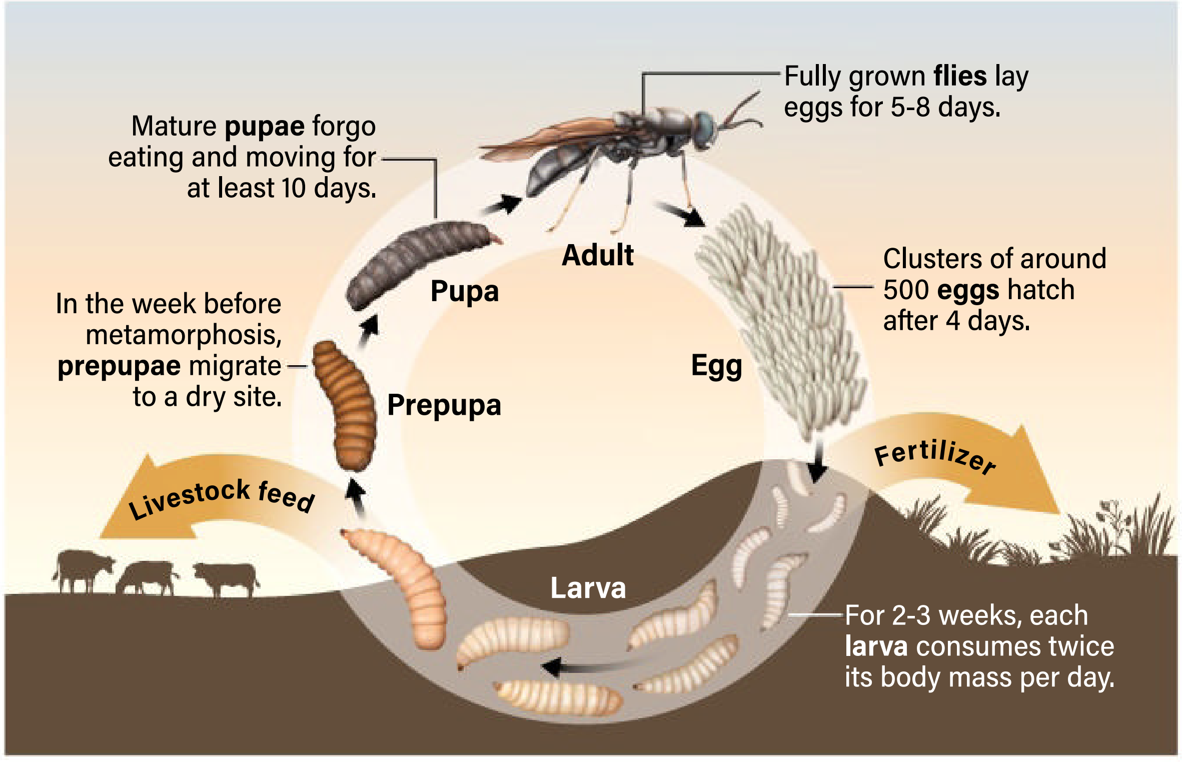
PREVIOUS PAGE: DANNY RADIUS/SHUTTERSTOCK. THIS PAGE: VIJIN VARGHESE/SHUTTERSTOCK

During their two-week feeding period, the larvae do nothing but eat, growing to hundreds of times their original size and becoming a squirming mass of chubby grubs full of proteins and fats.

UNLIKE OTHER SPECIES of flies that lay eggs directly on a potential food source, black soldier flies lay their eggs (right) in nearby cracks and crevices.

consumption of fish and seafood has quadrupled. On average, we eat twice as much seafood today as we did five decades ago. That puts increased pressure on wild fish stocks, which can't reproduce fast enough to sustain their population levels.

SOLDIER FLY LIFE CYCLE


Fully grown **flies** lay eggs for 5-8 days.
Mature **pupae** forgo eating and moving for at least 10 days.
Adult
Pupa
Clusters of around 500 **eggs** hatch after 4 days.
In the week before metamorphosis, **prepupae** migrate to a dry site.
Egg
Prepupa
Fertilizer
Livestock feed
Larva
For 2-3 weeks, each **larva** consumes twice its body mass per day.

FROM TOP: INNOVAFEED; TOMASZ KLEJDYSZ/ISTOCK VIA GETTY IMAGES; ROEN KELLY/DISCOVER

To fulfill demand, the aquaculture industry — responsible for raising fish and other seafoods in enclosed pens — has grown rapidly. In 1990, world aquaculture produced about 17 million tons annually. By 2018, production had risen to over 114 million annual tons.

Although that's helped meet world demand, it puts correlating pressure on the nutrients needed to feed farmed salmon, shrimp and catfish. Somewhat ironically, aquaculture feed is usually made with fish oil and fishmeal. Feeding fish to fish and other aquatic species at a time when the world's wild fish populations are diminishing portends a practice with an unsustainable future.

It's a conundrum for sure: a growing world population and a food supply chain that's facing fewer, more expensive resources. In the ongoing search for alternative sources, however, *H. illucens* keeps showing up as an admirable problem-solver. For example, a study in the *Journal of Economic Entomology* concluded that substituting chicken feed made from BSF meal for traditional soy-and-fishmeal feed resulted in a 25 percent better return on investment for farmers.

Cost-effectiveness comes naturally to commercially farmed *H. illucens*, thanks to the fly's obliging life cycle. It's happy to eat waste products that are cheap, if not altogether free, and it doesn't need a lot of dining space. Given the right temperature and humidity, BSF larvae can thrive at densities of more than 140,000 larvae per cubic foot.

When ready to turn into flies that actually fly, mature pupae willingly self-segregate themselves from their fellow larvae and food substrate — no human-made mechanism or manual labor is required. They crawl into a nice, dark, pre-made pupal haven and metamorphose into flies that, during their brief seven-day existence, cruise

IN 2020, InnovaFeed unveiled its second black soldier fly factory, in Nesle, France — the world's largest at the time.

about in screened enclosures, seeking only to mate. Females lay up to 500 eggs, depositing them in perforated containers designed for the purpose. In commercial operations, fly development, mating chambers and eggs depositories can be compactly combined, with one leading to the other.

A 1-acre BSF facility can produce the same amount of protein and fats as a 2,500-acre cattle farm or 100 acres of soybeans, greatly reducing the water requirements, production costs and carbon footprint per pound of protein produced. It's good supporting data for our fly-as-hero construct, but a goal as ambitious as saving the world doesn't get off the ground without substantial capacity and profitability baked into the equation. And that's where *H. illucens* really stands out.

IN THE GENTLE flatlands of the central Midwest, where fields of corn and soybeans stretch to the horizons, agricultural giant Archer-Daniels-Midland is building a 750,000-square-foot black soldier fly facility. When complete, the Decatur, Illinois, plant will farm billions of *H. illucens* larvae in stacked bins that provide 8.6 million square feet of breeding surface. The goal is to annually produce 60,000 tons of protein product, 20,000 tons of oil, and 400,000 tons of frass.

The ADM plant is being designed and set up in partnership with InnovaFeed, a Paris-based biotech company that specializes in developing industrial-scale black soldier fly breeding and processing facilities. If that sounds niche, consider that in addition to the ADM facility, InnovaFeed has already established two such industrial plants in France and has plans to build 10 more in various locations around the globe by 2030.

"We believe innovative insect-based food solutions can help us live how we want to live, without compromise," says InnovaFeed's co-founder and president, Clément Ray. "To achieve

STOMACHING BUGS

While producing mass quantities of animal feed is a worthy goal for *H. illucens*, the ultimate challenge awaits: feeding humans. The notion goes beyond novelty and commercial viability — it may be an absolute necessity for global food security in the coming decades.

In swoops the BSF. Anthropo-entomophagy — humans consuming insects — has been around for millennia and is still practiced in various tropical countries where edible insects are abundant and culturally acceptable as foodstuffs. Mealworms, crickets and ants are popular menu items. Even in highly developed parts of the world, including much of North America and Europe, a cottage industry has sprung up based on edible-insect novelty foods: barbecue-flavored mealworms, cricket flour, fruit-flavored suckers that house whole scorpions.

The black soldier fly doesn't yet have a significant presence in the novelty food market, despite pioneers such as Mark Nagy, author of the blog *The Future of Edible*

FROM TOP: INNOVAFEED (2); LIGHTSPRING/SHUTTERSTOCK

BECAUSE ADULT black soldier flies begin mating during flight and require temperatures of around 80 degrees Fahrenheit, they are often housed in large, climate-controlled fly cages.

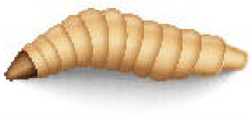
so, InnovaFeed is developing highly versatile ingredients that can be easily integrated in a wide variety of applications. We invest a lot in [research and development], both internally and with emblematic food industry partners, in order to be the first global player to unleash the potential of *Hermetia*."

One of the keys to InnovaFeed's unleashing is "industrial symbiosis," a strategy of nestling black soldier fly food sources and breeding units as close as possible to food resources and facilities that make BSF-based feed and fertilizer. That saves energy costs for transportation and storage and lowers the overall carbon footprint of the operation.

The ADM plant in Decatur, for example, will feed its hungry BSF larvae corn products such as stalks and leaves taken from surrounding farms — a use of byproducts that otherwise have little value as a commodity. The proximity means that the byproducts don't have to be dried and stored to preserve them for shipping. Ray says the methods employed at the ADM plant will result in an 80 percent reduction in carbon emissions compared to the rest of the animal-feed industry. "This unique model allows us to deliver the best environmental performance," he notes.

While ADM's new plant is a giant step toward large-scale utilization of the black soldier fly, there are hurdles yet to cross.

The Association of American Feed Control Officers works with the FDA to approve the safety and composition of feed-grade materials in North America. In 2016, they gave the thumbs-up for the dried larvae of *H. illucens* to be used for feeding farm-raised salmon and trout and extended the approval to poultry in 2018. But use for beef cattle and swine has yet to gain approval; ongoing concerns include the type of substrate on which the fly is fed. Raising flies on entrails, internal organs and manure is a definite no-no. And feeding the fly processed versions of itself raises the specter of mad cow disease, the infamous livestock sickness that spreads when healthy cows eat feed containing processed beef from infected ones. Plus, regulatory controls vary by nation, complicating and impeding potential international commerce of BSF products.



BSF animal feed also faces headwinds because the product is relatively new to commercial livestock farmers — substantial purchases of it aren't yet an industry norm. Harald Sveier, manager of research and innovation at Leroy Seafood Group in Norway, says his company buys about 9,000 metric tons of BSF-based fish feed every year, though he's concerned that the price is too high. "We hope that the price will come down as production gets more industrialized," says Sveier.

NEVERTHELESS, the story of how the black soldier fly comes to the rescue of the world's impoverished and undernourished is already in progress.

In Dar es Salaam, Tanzania, where the population center of Africa's sixth-largest city

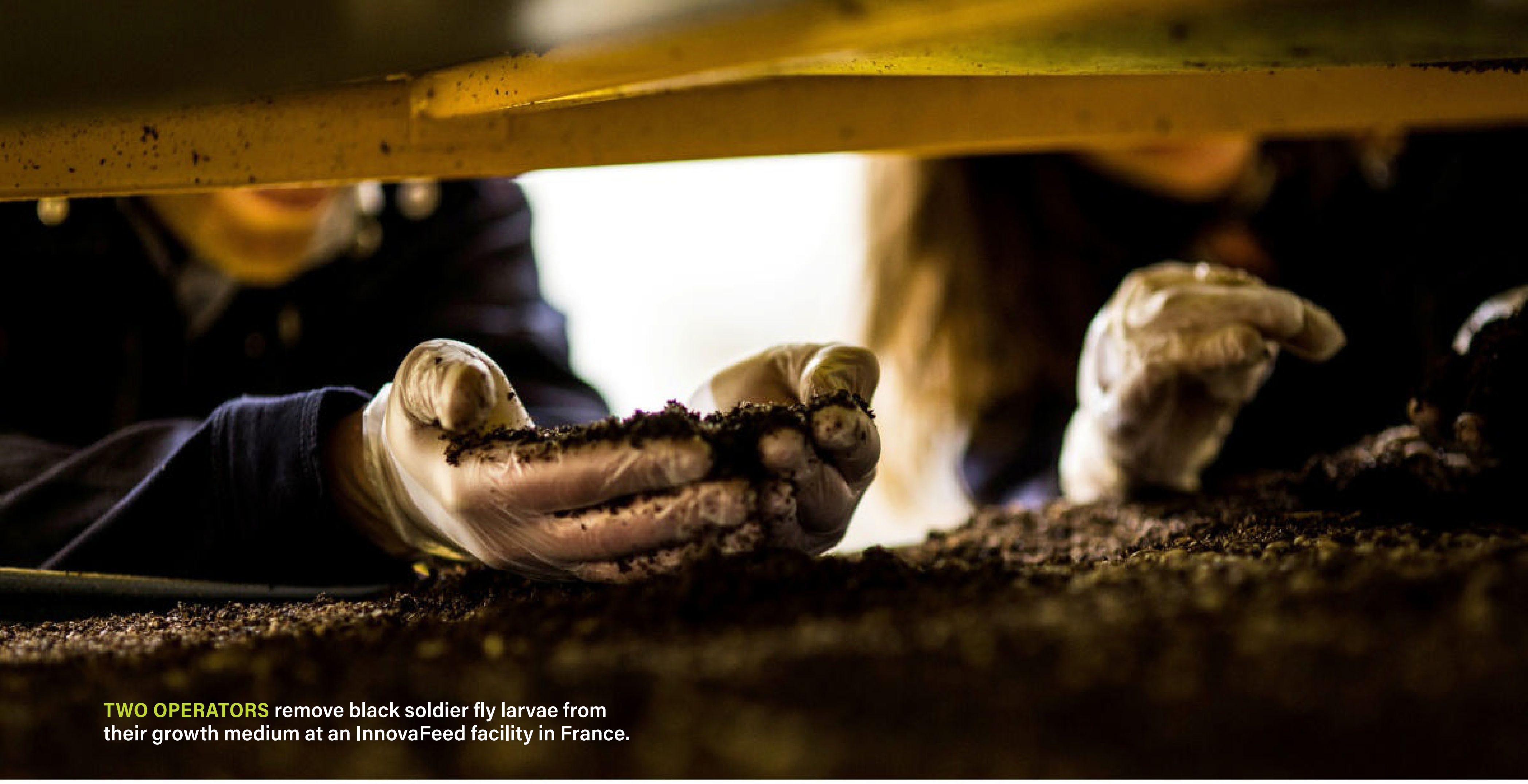
Insects, describing the larvae as possessing an "earthy, chocolate-like, malty, fish flavor." And Hui Ling Yu, a student at Xiamen University, recently published a paper touting BSF larval fat as a substitute for butter, noting that "the application of BSFL fat as a butter alternative shows a great potential for human consumption in [the] near future."

When it comes to approving insect-based foods for human consumption, however, the FDA is a bit of a muddle. On one hand, it identifies insects in human food as "filth," and offers wince-inducing guidelines for insect parts allowed per volume of common edibles. Apple butter, for example, cannot have more than five whole or equivalent insect parts per 100 grams — and not more than four rodent hairs, but who's counting?

On the other hand, the FDA allows espresso-flavored grasshoppers and other goodies to fall under its general guidelines that novelty foodstuffs should be free from choking hazards and pathogens. Compliance is self-regulatory under the latest version of the Federal Food, Drug, and Cosmetic Act, which says a food substance is safe if a manufacturer's hired experts deem it so.

Still, the idea of insects as the basis for burgers and brats is a high cultural hurdle for folks living in industrialized nations and for food suppliers hoping to profit in the world of mass consumerism. — J.R.

CLOCKWISE FROM TOP: INNOVAFEED; BIOBUU LIMITED; SERGII SYZONENKO/SHUTTERSTOCK



TWO OPERATORS remove black soldier fly larvae from their growth medium at an InnovaFeed facility in France.

sprawls against the Indian Ocean, is a 15-acre compost facility and a modest, 11,000-square-foot insect breeding facility. Inside, 30 million BSF larvae chew their way through 10 tons of hotel, market and restaurant waste each day. Running at its peak, the Biobuu Limited black soldier fly farm produces up to 2 tons of protein-rich fish feed supplement and 5 tons of organic compost daily.

"A lot of the waste that's produced in this region goes to landfills," says Biobuu Limited founder Kigen Compton in a company video. "So not only is it polluting the actual environment with smells, wastewater, etc., it's also contributing to greenhouse gases. By introducing the larvae, we solve that problem. So instead of a product that's going to contribute to environmental degradation, we're actually creating a product of value."

Biobuu's BSF facility in Tanzania is scheduled to be replicated on a newly purchased, 2-acre parcel in Mombasa, Kenya. "That makes it one of the biggest farms in East Africa," says Matthew Haden, commercial director of Biobuu. The company, which plans to build five more facilities throughout the region in the next few years, has also developed community insect bins throughout Tanzania, allowing locals to use their own waste to create insect protein.

"We can build facilities matched to the size of the community," says Haden. "Our insect bin designs use cinder-block construction, so that's relatively easy to do. Having a community waste-recycling facility saves municipalities money on trash pickup [and] reduces waste, and the fertilizer and insect protein made there is available to the community." With Africa's population projected to double by 2050, augmenting the food-supply chain and cost-effective waste management is of paramount concern.

The Food and Agriculture Organization of the United Nations estimates that nearly 800 million people faced hunger in 2020. For a world population expected to increase 30 percent by 2050, the implications are dire. So, too, is the looming reality that increasing worldwide food demand will severely strain essential resources such as land and water, while making adverse contributions to climate change. The fact that the black soldier fly will consume wastes, produce edible biomass and provide useful byproducts makes it an ideal component for the infrastructure of developing nations.

For smaller countries with remote villages, the possibility of a sustainable food loop comes into focus: Organic garbage deposited in community collection bins are fed to farmed fly larvae. The maggots dutifully digest stuff that would normally end up in a landfill, reducing waste that attracts rats and other disease vectors. Some larvae are harvested and used to feed locally farmed fish and poultry; others are kept for breeding new larvae. The frass is used as fertilizer for crops that feed both livestock and humans. To close the loop, leftover produce, crop waste and discarded animal products are returned to feed more fly larvae.

Matan Shelomi believes that the black soldier fly holds tremendous potential for microeconomies like those of the Pacific Small Island Developing States — a consortium of 20 oceanic nations including Palau, Tonga and Fiji — that are characterized by growing populations, limited resources and remoteness. "Setting up an insect farm is cheap, and maintaining

IN DECATUR, ILLINOIS, black soldier flies will soon provide tens of thousands of tons of insect oil and protein — as well as 400,000 tons of frass for fertilizer — every year.

INNOVAFEED (2)

A 1-acre BSF facility can produce the same amount of protein and fats as a 2,500-acre cattle farm or 100 acres of soybeans, greatly reducing the water requirements, production costs and carbon footprint.

SITE MANAGER Zacheriah Joseph sifts through food waste at Biobuu's black soldier fly facility in Dar es Salaam, Tanzania.

one requires little labor," says Shelomi. "Both are attractive features for farmers in developing economies that also stand the most to benefit from insects' nutritional status."

Although he acknowledges the merits of converting BSF biomass into livestock feed and human food, Shelomi says the more immediate need is using the fly to consume waste products before they can attract disease-carrying animals and threaten fragile ecosystems.

Case in point: the Republic of Kiribati, an archipelago consisting of 33 islands sprinkled across 1.3 million square miles of Pacific Ocean. Almost half of its inhabitants live in the capital city of South Tarawa, one of the poorest and most densely populated places on Earth. Only about 38 percent of the city's waste is collected; much of the remaining is illegally dumped into lagoons and the ocean, where it pollutes waterways.

"More than addressing hunger, addressing waste is the main benefit of BSF," says Shelomi. "Organic waste is a substantial proportion of world waste, especially in rural and developing communities, and much of it is currently landfilled or burned or illegally dumped. Turning trash into cash benefits everyone, so waste valorization of BSF will arguably be their best usage, so long as it is cost-efficient and profitable."

FOR TOMBERLIN, the pathway to efficient commercialization of the black soldier fly is to create smaller BSF facilities that take advantage of regional resources and can scale to local demands. To do that, he founded EVO Conversion Systems, a company that provides technical knowledge and equipment for farming *H. illucens*. With outside expertise, startups don't have to spin their wheels figuring out the best methodologies.

"The problem," says Tomberlin, "is that you're trying to be a waste-management company, you're trying to be a protein company, and you're trying to be an insect biologist, all at the same time, while trying to be an entrepreneur or a businessperson. And that's a lot of hats to wear and a massive burden for people to have to manage." Rather than one $50-million site, Tomberlin envisions several $500,000 sites, with a company like EVO at the hub. "What we're looking at is the evolution of the industry," he says.

It's a pragmatic way to harness the fly's potential. After all, even comic book superheroes sometimes need the help of everyday heroes to succeed. And with challenges for the planet mounting, from global hunger to climate disaster, the black soldier fly is poised to be, if not the savior, then certainly one of the keys to unlocking a more secure and stable future for many parts of the world.

John Riha *is the former executive editor of* Better Homes and Gardens *and writes the blog* Schiddygarden *from his home in southern Oregon.*

FROM TOP: BIOBUU LIMITED; SERGII SYZONENKO/SHUTTERSTOCK

SPACE AGING

Microgravity deteriorates the body in surprisingly familiar ways. Space travel is now informing health research for earthbound seniors and astronauts alike.

BY DAVE WILLIAMS AND ELIZABETH HOWELL ■ ILLUSTRATIONS BY KELLIE JAEGER

While paging through the book *Space Physiology and Medicine* in 1995, Senator John Glenn spotted a chart that captured his imagination. Listed were 52 kinds of physical changes routinely experienced in space by orbiting astronauts, including osteoporosis, cardiovascular difficulties and alterations in the distribution of body fluids. The 73-year-old Glenn, who had spent years on the Senate Special Committee on Aging, realized that he was looking at a list of complaints common to seniors — yet the typical astronaut was in their 30s, 40s or 50s.

Given the similarities, Glenn wondered if there were any plans to fly senior citizens into space. He called the authors of the publication along with other space doctors to find out. To his surprise, despite shuttle missions going up every few months, nobody knew of any plans to send an elderly person into orbit. "I wondered why the science had to wait," Glenn wrote in his autobiography. "Shuttle flights were going up regularly. Why couldn't room be made on one of them for some experiments on senior citizens? And then I began to think, 'Why not me?' "

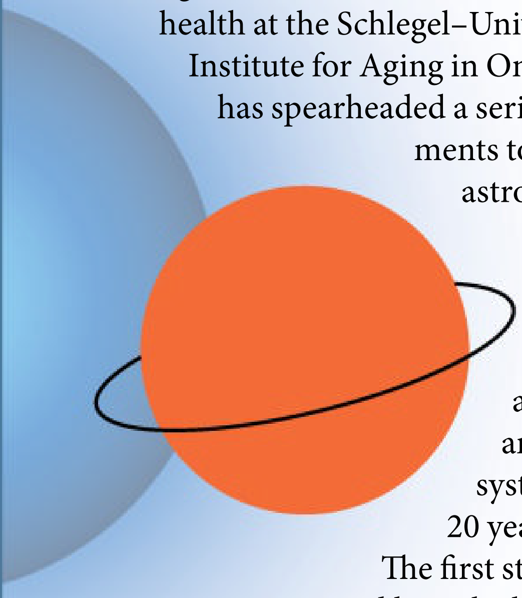
Early in his career, Glenn trained as a Marine and was an accomplished test pilot, breaking numerous flying records before being scooped up by NASA in the very first astronaut-recruitment drive. Famous for his clean-cut image and charm, he was a favorite to be the first to fly in space. Indeed, he was on NASA's first orbital mission, *Friendship 7*, in 1962. But his plans for a return to space were stymied by the Kennedy administration, which deemed Glenn too valuable a national hero for such a trip. So, Glenn left NASA and moved into politics, never expecting that the chance for space travel would come up again.

Several things played into Glenn's favor as he lobbied NASA in 1995 for a flight opportunity. The agency was, of course, wary of sending a senior into space — let alone one as famous as Glenn, a politician for decades. Yet NASA did have 42 years of data on the astronaut, who had consented to regular medical checks under an agency program for retired astronauts. Glenn was also in remarkably good health, with one *Washington Post* report describing him as “one very fit, lifelong jet jockey who power-walks two miles a day on Earth and has passed all his preflight physical tests.”

Glenn told NASA that this was not simply a bid to get himself one last joyride in space. There has always been a relationship between studies on Earth and those in space, with terrestrial research helping humans travel farther and stay longer in orbit while space research transforms the way we live on the ground. In 1997, pointing out that many countries were wrestling with the issue of caring for their aging populations, Glenn’s hope was that the spaceflight would have “enormous benefit for — well, the graying of nations, they call it, all over the world.”

MICROGRAVITY — a near absence of gravity while in orbit — temporarily induces many of the effects of aging even in younger crew members, though it appears these effects are largely reversible over time once the astronaut reaches the ground. Now, an exciting new area of investigation into this apparent accelerated aging, its underlying mechanisms and possible preventive strategies could help both astronauts and seniors improve their resilience and decrease the risk of disease.

Among the scientists conducting this research is Richard Hughson, the research chair in vascular aging and brain health at the Schlegel–University of Waterloo Research Institute for Aging in Ontario. Since 2007, Hughson has spearheaded a series of four Canadian experiments to investigate in detail why astronauts age rapidly in space, and what countermeasures can be put in place to prevent and reverse this sudden aging. He has found that “during a six-month space mission, an astronaut’s cardiovascular system can age by up to 10 or 20 years.”



The first study, which ran from 2007 to 2010, examined how the hearts and blood vessels of astronauts alter due to spaceflight. It followed six astronauts who strapped on devices that examined their heart rate, blood pressure and physical activity in several 24-hour periods before, during and after their mission. This allowed the investigation team to see how their systems changed in space and how exercise and other countermeasures — for example, wearing devices to adjust blood flow — would be helpful.

The success of this study then spurred the Vascular Series, which comprises three sets of experiments to date. The first, Vascular, looked at changes in the blood vessels and the heart over time, specifically examining how arteries change and stiffen as blood pressure alters due to less physical activity in space. Artery stiffening then came under even more scrutiny in Vascular Echo, which required astronauts to wear a leg cuff that shifted blood from the upper body to the lower body, better mimicking proper blood flow on Earth. Vascular Echo additionally monitored astronauts for a year postflight to investigate how the body readjusts after a long-duration stay on the space station.

The latest in the series, Vascular Aging, looks at how and when insulin resistance may happen during a space mission. It also examines how radiation exposure may affect cardiovascular health and, like Vascular Echo, explores how well an astronaut recovers after coming back to Earth. Vascular Aging began collecting data in 2019 and will finish in 2024, according to the Canadian Space Agency.

So far, the preliminary results from Vascular show that arteries of astronauts tend to stiffen by 17 to 30 percent. Astronauts may also be at increased risk of Type 2 diabetes because they develop insulin resistance and have difficulties processing glucose. “We are seeing astronauts coming back from space with carotid arteries that have aged the equivalent to 20 to 30 years in stiffness,” Hughson told the Canadian Institutes of Health Research in a 2015 interview about Vascular. “It is very comparable to what you would see in an aging population.”

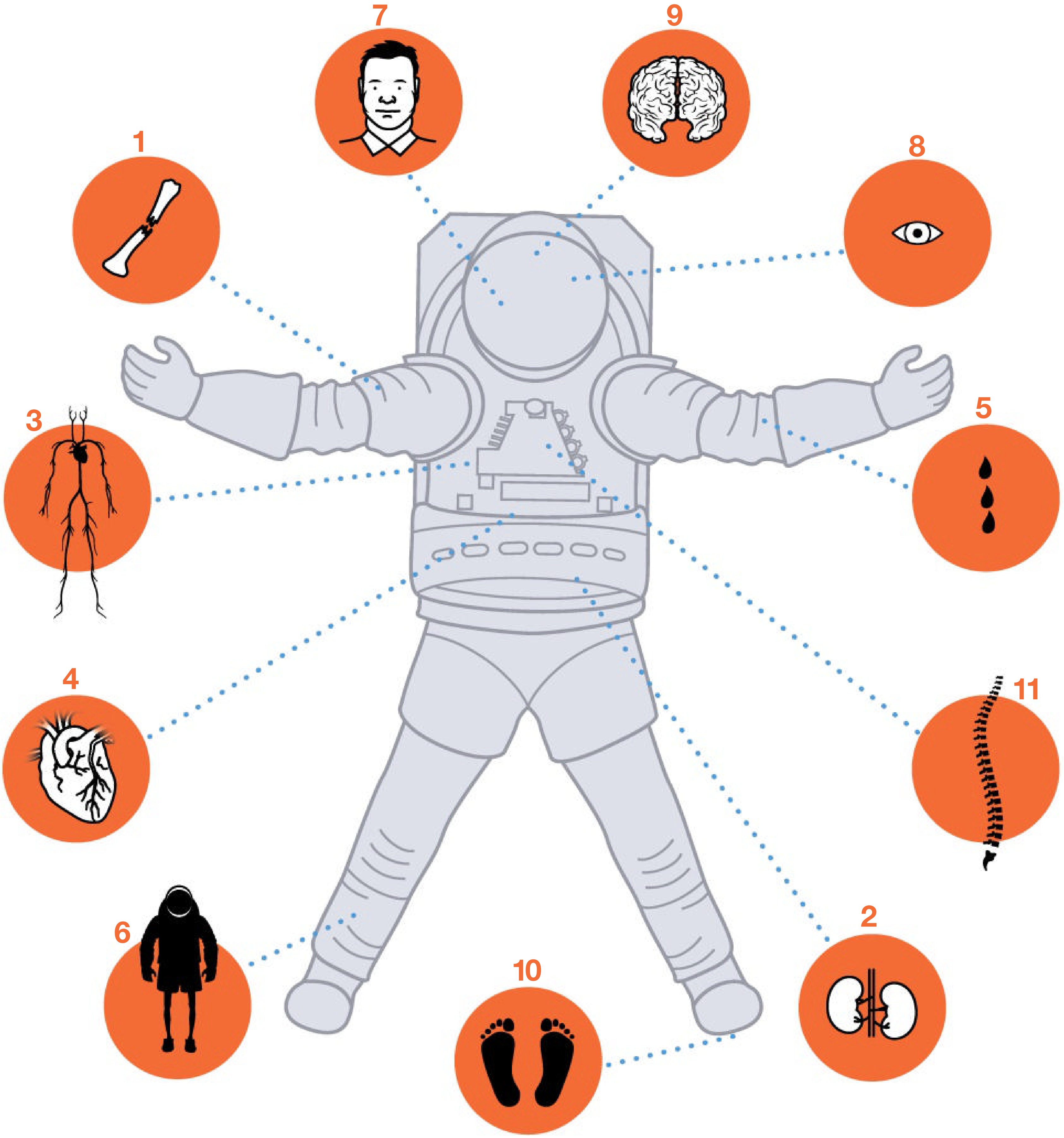
AN ASTRONAUT returning to Earth arrives much like a delicate senior who may have several health issues that prevent them from moving for long periods of time. After all, astronauts don’t work very hard to move from place to place in space. Their lungs, without proper exercise, become deconditioned. Even the soles of their feet become soft from disuse as they float around.

They’d be next to helpless upon landing on Earth without countermeasures in space, including a tailored exercise regime. The aim, for the first few months or so back on the ground, is to get the astronaut back to a typical state of middle age: able to drive, exercise, actively participate in work and home activities, and continue contributing to research and other missions at NASA.

After Christina Koch spent nearly a year in space, the agency published 10 ways in which the healthy 41-year-old might need to recover when coming back to Earth. Coming back meant, for example, that sleep would no longer be simple floating bliss, that smells would suddenly be frequent and that sensory inputs like wind on the face would suddenly happen again. Changes to weight and balance were also taken into account.

“On Earth we rely on our eyes and inner ear to maintain stability. In orbit, without gravity pulling down, the mind quickly stops listening to the inner ear. The eyes take over … we rely solely on visual cues,” Koch said in the article. “From what I’ve been told, it takes a couple days after landing for the mind to start listening again. The human body’s ability to adapt to its environment is nothing less than impressive.”

The recovery from space actually begins as astronauts dress for the ride home. Both NASA and Roscosmos,



EFFECTS OF MICROGRAVITY OVER TIME

BONE DENSITY LOSS:
- **1-**Premature osteoporosis
- **2-**Increased risk of kidney stones

CARDIOVASCULAR CHANGES:
- **3-**Stiffer arteries
- **4-**Change in heart shape
- **5-**Insulin resistance

BODY FLUID SHIFTS:
- **6-**Skinny "bird" legs
- **7-**Puffy face and neck
- **8-**Impaired vision
- **9-**Swelling of the brain

OTHER ISSUES:
- **10-**Softened soles of feet from disuse
- **11-**Elongation of the spine

NASA

THE LONGEST SENIOR STINT IN SPACE SO FAR STILL BELONGS TO NASA'S JOHN GLENN, WHOSE FLIGHT CAPTIVATED THE IMAGINATIONS OF YOUNG AND OLD ALIKE IN 1998.

the Russian space agency, use garments with lower-body compression to assist with adjusting fluid shift. NASA continually refines the design by studying test subjects following a period of bed rest and, of course, spaceflight. The agency notes that the garment also has applications for people on Earth who have a tendency to faint or experience difficulties in blood pressure.

Even before they go to space, NASA establishes a baseline for each astronaut to customize their rehabilitation program for their return. In other words, they make sure to tailor the training so that the astronaut is at a level of capability after the recovery period that is similar to their fitness before traveling to space — rather than aiming for an idealized standard that may not be fit for all bodies. The rehabilitation period is lengthy, and numerous astronauts have pointed to the need to take it easy and receive assistance from family members during this delicate time, which can last months.

"Postflight reconditioning begins on landing day, is scheduled for two hours per day, seven days a week for 45 days and is tailored to the specific needs of the astronaut," reads a postflight reconditioning brief on NASA's Technical Reports Server from 2011. Fortunately, the specialists assigned to help each astronaut recover have more than two decades of experience working with ISS crew and know what sorts of countermeasures are required to keep the returning space flyers safe and healthy.

For seniors, the implications cannot be clearer: There is more that must be done as people age to counter the effects of staying sedentary. Many doctors have pointed to the risk of sedentary work for industrial populations in general. But this newer research underlines the need not only for exercise, but for consistent exercise.

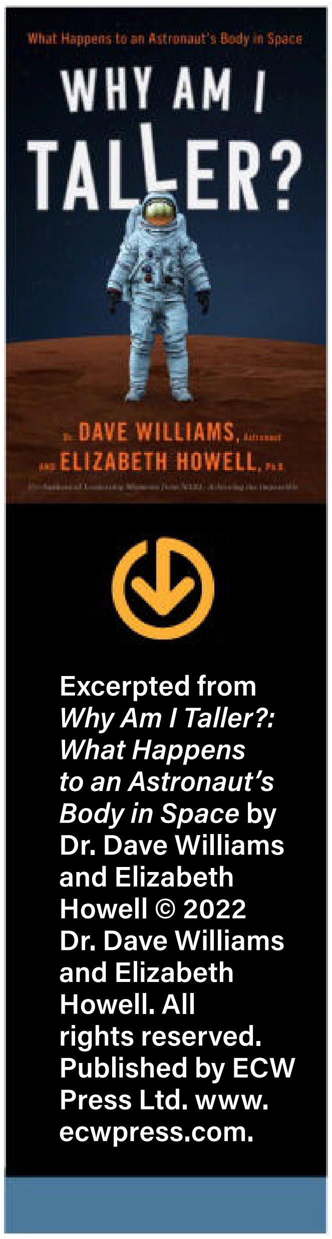
WE HAVE AMPLE evidence showing how dramatically younger astronauts age in space, and the research on reversing this aging can be applied to improve the health and lives of elderly people on Earth. But space-flying seniors remain a small and select group. The eldest so far — Wally Funk, 82, and William Shatner, 90 — experienced suborbital flights of only a few minutes long in 2021. Both appeared energetic in media interviews post-landing, although detailed medical results were not disclosed.

The longest senior stint in space so far still belongs to NASA's John Glenn, whose flight captivated the imaginations of young and old alike in 1998. At age 77, Glenn flew as a payload specialist on the STS-95 Spacehab mission, meaning he was responsible for some of the many life-science and microgravity experiments on board. All reports indicate that he was careful to contribute; a media report said he "received good reviews for his work ethic and affability" and didn't bother himself with the attendant celebrity that his name could have brought. On board the mission, he made sure to fulfill crew responsibilities of not just experiments but also housekeeping and meal preparation.

Glenn performed several experiments on himself in space, sometimes with the assistance of fellow astronaut Scott Parazynski, a medical doctor who was on board with him. Metabolism experiments had him swallowing one kind of amino acid in pill form and another kind by injection, as proxies for hormonal changes caused by muscle atrophy or protein loss. X-ray studies recorded changes in lean body mass. Glenn also charted his sleep patterns on four nights, comparing the results of taking melatonin or placebo pills, and tracked his core body temperature with a mini thermometer embedded in a capsule he had swallowed. His brain waves were monitored using devices clamped to his scalp, wrist and chest, and — like many other astronauts — he gave samples of blood and waste for analysis.

The big questions today are which senior will be the next to participate in an extended orbital mission, and what new information may we collect from them? The key is to find someone willing to continue to participate in medical experiments — and to properly calibrate each result to match up with Glenn. ◼

Dave Williams *is the former director of space and life sciences at NASA's Johnson Space Center, and has flown in space twice.* ***Elizabeth Howell****, a space journalist for 20 years, is a staff writer for Space.com.*


What Happens to an Astronaut's Body in Space
WHY AM I TALLER?
Dr. DAVE WILLIAMS, Astronaut
and ELIZABETH HOWELL, PhD

Excerpted from *Why Am I Taller?: What Happens to an Astronaut's Body in Space* by Dr. Dave Williams and Elizabeth Howell © 2022 Dr. Dave Williams and Elizabeth Howell. All rights reserved. Published by ECW Press Ltd. www.ecwpress.com.

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A.

B.

I guess I was a little bored. For the past hour, I'd been on the phone with Daniele, the head of my office in Italy, reviewing our latest purchases of Italian gold, Murano glass and Italian-made shoes and handbags.

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BY ELIZABETH HEATH

LAMBERTO BERNARDINI (right) crafts a modern version of L'Orvietan in a laboratory (left) that mixes the modern and the historic. The space also displays his collection (below) of antique jars, recipes, licenses and books related to the herbal remedy.

A Cure-All's Comeback

WITH INGREDIENTS RANGING FROM ACCEPTED HERBAL TREATMENTS TO BURNT VIPER'S FLESH, L'ORVIETAN WAS THE 17TH-CENTURY REMEDY OF CHOICE FOR COMMONERS AND KINGS.

"Whoever studies the history of medicine finds L'Orvietan," says Lamberto Bernardini.

In his laboratory in Orvieto, Italy, a medieval hill town famous for its soaring duomo, that history is all around. Bernardini's vaulted, frescoed space dates to the 1200s. One of the rooms in his lab is a museumlike space filled with historic books and framed antique letters, advertisements, and certificates. Centuries-old apothecary jars line the wooden shelves, their labels hand-painted in Italian script: *angelica*, *genziana*, *mirra*. Separated by a glass wall, the other room could be a medieval alchemist's studio were it not for the modern stainless steel vats, which sit amid rows of glass bottles and stacks of cartons and labels.

It's here that Bernardini brews up his 21st-century version of an old and storied recipe. Through a hobby that became a passion that became a vocation, he's revived a 17th-century formula for L'Orvietan, an herbal antidote and cure-all that was known throughout Europe and Britain. The remedy even made it as far as North America in the hands of missionaries and explorers: At Michigan's Colonial Michilimackinac historic site, a lead cap found in the excavation of a 1700s rowhouse was recently identified as the lid to a L'Orvietan bottle.

Bernardini now sells L'Orvietan as a digestif — a liqueur that's likely much more palatable than the original mixture, which would have been sold as a powder, paste or syrup. The history he's helped uncover sheds light on a product that was coveted by the kings of France, sanctioned by popes, sold by traveling charlatans, and earned mentions in the works of Molière, Voltaire and Balzac.

THE ANTIDOTE has been in the historical record since 1603, when Girolamo Ferrante, considered the inventor of the herbal remedy, was granted permission to sell it in the public square in Orvieto. Whether the product had an official name before that is unknown, but Ferrante is referred to in the document as *L'Orvietano* — the man from Orvieto — and his product was thereafter known as *L'Orvietan*.

A traveling salesman who wasn't actually from Orvieto, Ferrante moved about Italy and sold his cure to crowds that would assemble in the piazzas. He probably worked from a raised stage so that he could shout to the assembled townspeople, and very likely peddled

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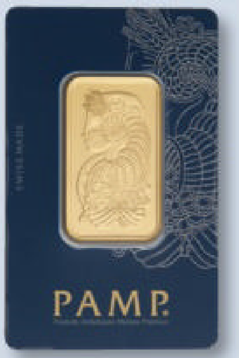

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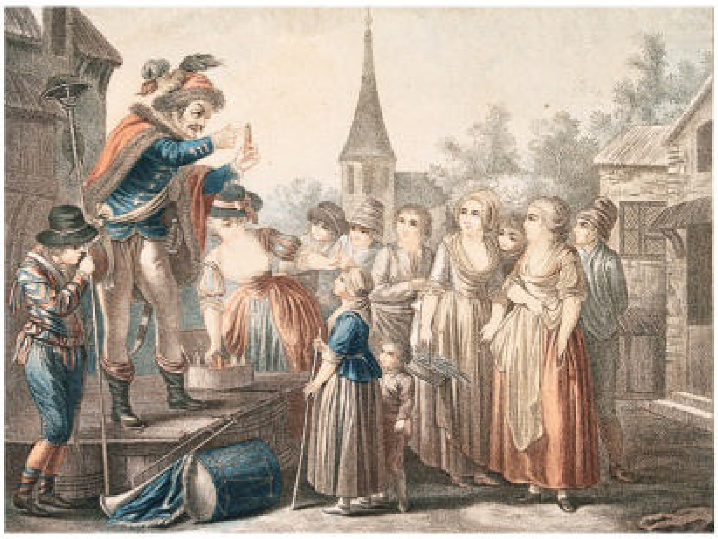
his wares with a healthy dose of theatrical flair in the form of dramatic sketches that would end with the sick being cured once L'Orvietan was administered.

Ferrante fought to protect his patent and authority to sell the original L'Orvietan, but within a few years, scores of other formulas, either claiming to be the original or of similar benefit, had sprung up across Italy and the rest of Europe. L'Orvietan outlived Ferrante, who died in 1640. His widow's second husband, Cristoforo Contugi, presented it to Louis XIV and in 1647 earned the *privilège du roy* — "the king's privilege" — to sell it, but even the favor of the king didn't last. Eventually L'Orvietan, like so many other patent remedies before it, passed into obscurity.

THE DUOMO, OR CATHEDRAL, rises above the Italian town of Orvieto. The structure dates, like Bernardini's lab, to the 1200s. Traveling salesmen hawked remedies like L'Orvietan in nearby piazzas (right) throughout the 1600s.

L'ORVIETAN
ORVIETAN



Bernardini had to travel across Europe on the trail of L'Orvietan. He scoured historic archives and antique-book stores. He acquired rare medical books and documents, and met with scholars, herbalists and pharmacists. Finally, in a Venice library, he found the missing link in his search: a 1623 recipe, written by Ferrante's son Gregorio, which lists the ingredients, and, importantly, their measures, for the original L'Orvietan. Bernardini says he left just one ingredient out of his modern mix: burnt viper's flesh.

Yet the mixture of herbs that Ferrante developed and others copied wasn't necessarily all that original. L'Orvietan and its imitators had their roots in a more antique antidote called theriac. Theriac was a preferred preventive and cure of Roman emperors who were justly afraid of being poisoned, either from something slipped into their food or drink or by a venomous snake slipped into their bed at night. In fact, Theriaca Andromochas, developed by Nero's physician, also contained viper flesh — similar in concept to antivenoms made of snake venom — and became the gold standard of antidotes.

Theriac continued to be used as a cure-all and antidote for centuries, including throughout the Black Death years and well into Ferrante's time. But with its long list of as many as 80 ingredients and high status, theriac was expensive and exclusive. In L'Orvietan, Ferrante was able to reduce the number of ingredients and develop a product that he could claim worked just was well — and that the working classes across Europe could afford.

THROUGHOUT THE 1600s, L'Orvietan and its imitators were sold throughout Europe as a cure for stomachaches, shortness of breath, dizzy spells, and lovesickness, and as an antidote to poison — which in historical context could have meant any number of things, including fever, foodborne illnesses, and constipation. And, according to modern scholars, L'Orvietan's curative claims probably weren't just

TOP, FROM LEFT: DANCAR/SHUTTERSTOCK; BONNET AFTER P. CARÊME/WELLCOME IMAGES

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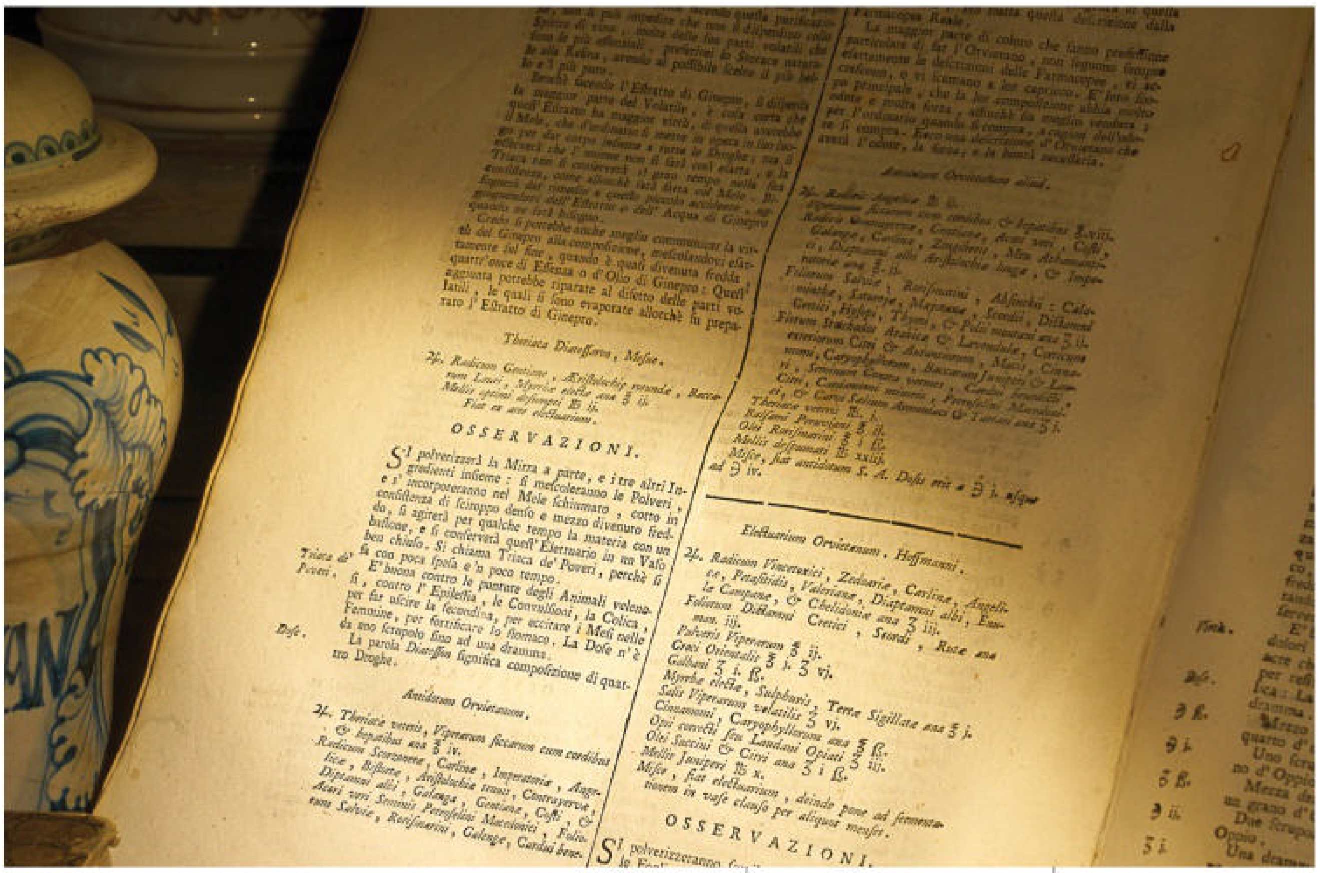


THERIACA
M. DCC. LXXXII

A PRECURSOR to L'Orvietan, theriac had ancient roots as an antidote crafted for Roman emperors afraid of being poisoned. (Note the snakes on the jar.) L'Orvietan used far fewer ingredients, making it more affordable.

pre-Enlightenment quackery. Historian David Gentilcore, who devotes a chapter of his book *Healers and Healing in Early Modern Italy* to L'Orvietan, explains that in Ferrante's era, "disease was seen as an accumulation of poison in the body, whether that meant you'd actually been poisoned, or you ate the wrong kind of food." The objective of taking a remedy like L'Orvietan was often to defecate or vomit, to get relief from symptoms rather than to find a cure in the modern sense, he says. In modern terms, Gentilcore likens L'Orvietan to aspirin — used to manage pain and allow people to resume their work.

Some medical and pharmacological historians contend that there was another active ingredient in L'Orvietan and its contemporaries, which might have had even greater feel-good effects than all those other herbs and roots combined. "Many secret remedies were big successes, and some seem to have actually worked," says Dutch pharma-historian Wouter Klein. Theriac and its precursor, mithridatium, were listed as ingredients in many versions of L'Orvietan (though, curiously, not in the Gregorio Ferrante recipe). And the principal ingredient of both these ancient cures, says Klein, was opium. "I think we can safely assume that any effect of L'Orvietan in the past depended on the level of opium in it," he says, and that the other ingredients were there "for color, taste, smell, or simply to make it more fancy, more expensive, and more difficult to counterfeit." He suggests that the popularity of the remedy may have had a lot to do with its consumers' opium addiction.

But L'Orvietan's non-opiate ingredients might not

Bernardini says he left just one ingredient from the original L'Orvietan recipe out of his modern mix: burnt viper's flesh.

WHEN *CHARLATAN* WASN'T A BAD WORD

What do you think of when you hear the word *charlatan*? A quack? A snake-oil salesman? A faker and a thief? In its original usage, *charlatan* didn't have any of those negative connotations.

Charlatan, or *ciarlatano* in Italian, is a combination of two words, *ciarla* and *cerretano*. *Ciarla* means "to chatter." *Cerretani* were men from the Umbrian town of Cerreto di Spoleto who were licensed to travel from town to town to collect alms. As a side business, they took up selling cures, including L'Orvietan. Their sales pitches, whether soliciting donations or selling their wares, involved lots of *ciarla*. In the vernacular of the day, these beggar-peddlers from Cerreto became known as *ciarlatani*.

When doctors and pharmacies started selling L'Orvietan and similar cures, they used their credentials to differentiate themselves from the *ciarlatoni*: "Who do you trust? Me, a trained doctor, or that *ciarlatano* shouting out on the piazza?" Their tactics worked and, over time, the pejorative meaning of *charlatan* stuck. — E.H.

RIGHT: JEBULON/WIKIMEDIA COMMONS

MARINA GRAU/SHUTTERSTOCK

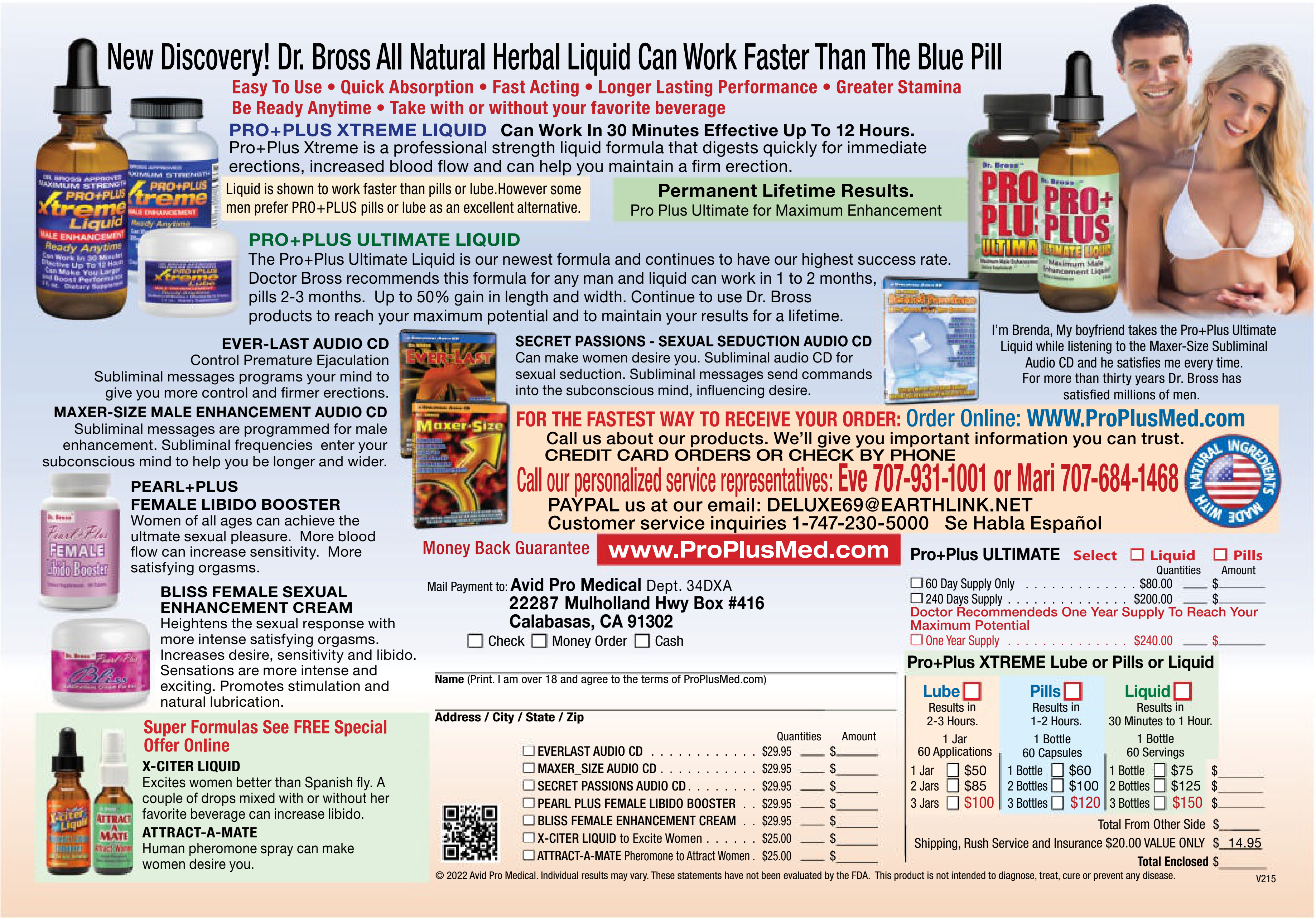
have been just filler. Victoria Sweet, a doctor of internal medicine who has a Ph.D. in medical history and premodern medicine (particularly the work of Middle Ages abbess and medical practitioner Hildegard von Bingen), points out that many of the herbs used in Ferrante's formula have accepted uses in modern herbal medicine. For example, "lavender is still used for relaxation and to decrease insomnia," says Sweet. "Rhubarb and mallow — these are considered digestive aides."

And it's not just herbalists who put stock in these old-world cures, says Sweet. "Big pharma is taking basic remedies and researching them to find what they could slightly change and patent." For instance, theophylline, a common asthma drug sold under several different brand names, has as its active principle black tea, which Sweet says has "long been used cross-culturally to open up the lungs." Poultices made from vinca (periwinkle) leaves have traditionally been used for drawing pus out of cankers and infections. And vinca alkaloids derived from that same family of plants, says Sweet, were developed into two standard chemotherapy drugs.

Gentilcore, who considers the claims that L'Orvietan contained opium credible but unprovable, emphasizes that at the time, L'Orvietan and contemporary cures weren't "alternative medicine," as herbal cures are considered today. While modern medicine offers more reliable results, in its historical context, L'Orvietan likely sold as well as it did because, to a certain degree at least, it was perceived to work. "Ferrante was using the science of the day. Viper's flesh may sound ludicrous to us, but every ingredient — and there were a lot of them — could be justified. And that's why he got a license to sell it. Medical authorities could understand it and had no problems with it," he says.

In an era where the overall state of health was poor, infant mortality was high and typical illnesses would have included fevers, consumption, gastrointestinal diseases, lice, scabies and syphilis (not to mention recurring bouts of the plague), L'Orvietan, says Gentilcore, "would have worked as well as any other medicine of the time." ◼

***Elizabeth Heath** is a widely published writer and editor based in central Italy, where she has lived for 13 years. She has never consumed viper's flesh, burnt or otherwise.*



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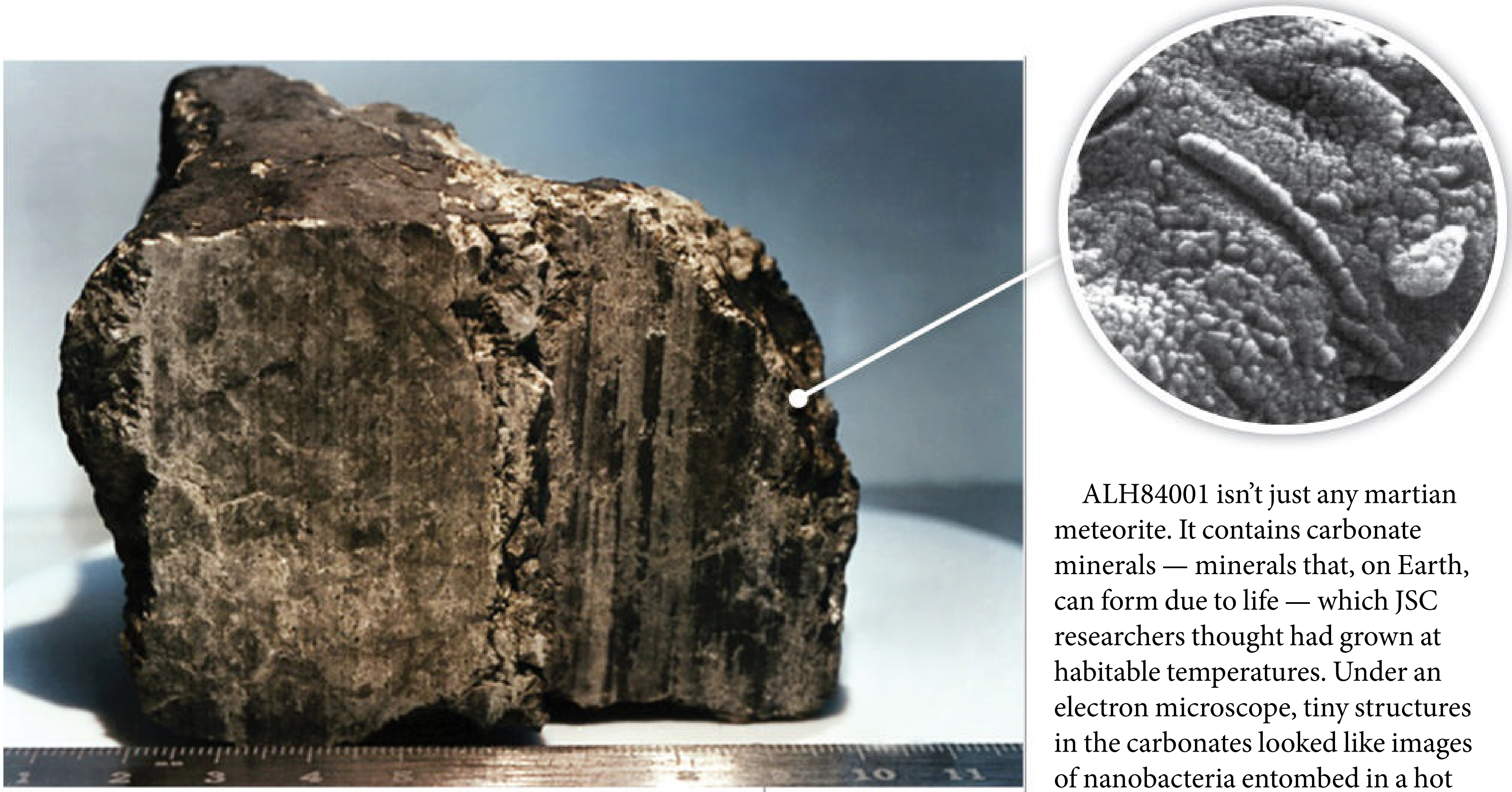
BY ELISE CUTTS



DISCOVERED IN 1984, the Mars rock known as ALH84001 was eventually found to contain carbonates — a possible sign of life once existing on another world. The press went wild and ALH84001 became a literal rock star.

New Life From an Old Rock

HOW A HUMBLE METEORITE REDEFINED THE FUTURE OF ASTROBIOLOGY.

In 1995, NASA was strapped for cash — and the search for life beyond Earth looked like it could be in trouble.

Years of steep cuts had reduced the space agency's five-year budget plan by just over 30 percent. Interest in exobiology — the study of the origins, evolution, and distribution of life in the universe — had been drying up for decades. After the 1976 Viking lander's life-seeking experiment on Mars came up empty, NASA cut down on Mars missions. Congress canceled NASA's Search for Extraterrestrial Intelligence program in 1993, after less than a year of operation. And in 1995, the Clinton administration called for more than $5 billion in additional reductions to NASA funding before the new millennium.

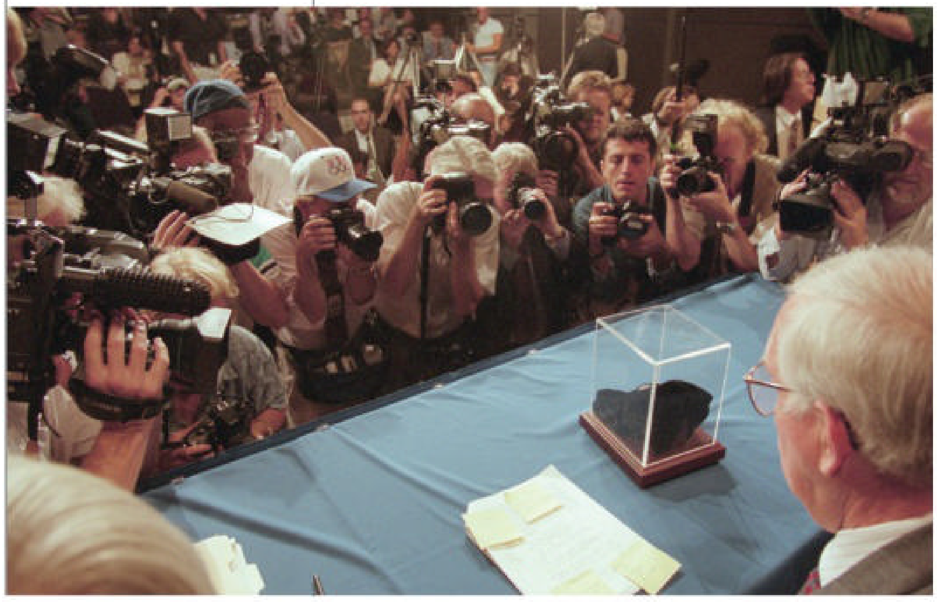
"Then a miracle happened called ALH84001," says Wesley Huntress, then NASA's associate administrator for space science. "And that just galvanized the public interest in what we were doing."

A potato-sized lump of 4-billion-year-old, grayish-green rock from Mars, ALH84001 fell to Earth some 13,000 years ago. Researchers found it in the Allan Hills region of Antarctica on a meteorite-hunting expedition in 1984, and brought to the Meteorite Processing Laboratory of the Johnson Space Center (JSC), where the rock's martian origin was discovered almost a decade later in 1993.

ALH84001 isn't just any martian meteorite. It contains carbonate minerals — minerals that, on Earth, can form due to life — which JSC researchers thought had grown at habitable temperatures. Under an electron microscope, tiny structures in the carbonates looked like images of nanobacteria entombed in a hot spring mineral deposit on Earth. These carbonates weren't enough to prove anything on their own, but they hinted that ALH84001 might be far more than just another space rock. So, in 1994, a JSC-led team quietly got to work taking a closer look at the meteorite.

TWO YEARS LATER, on Aug. 7, 1996, NASA announced that JSC's researchers believed that ALH84001 contained traces of ancient microbial life from Mars.

Suddenly, the search for life was back on. That same day, President Bill Clinton went on TV to promise that NASA would "put its full intellectual power and technological prowess behind the



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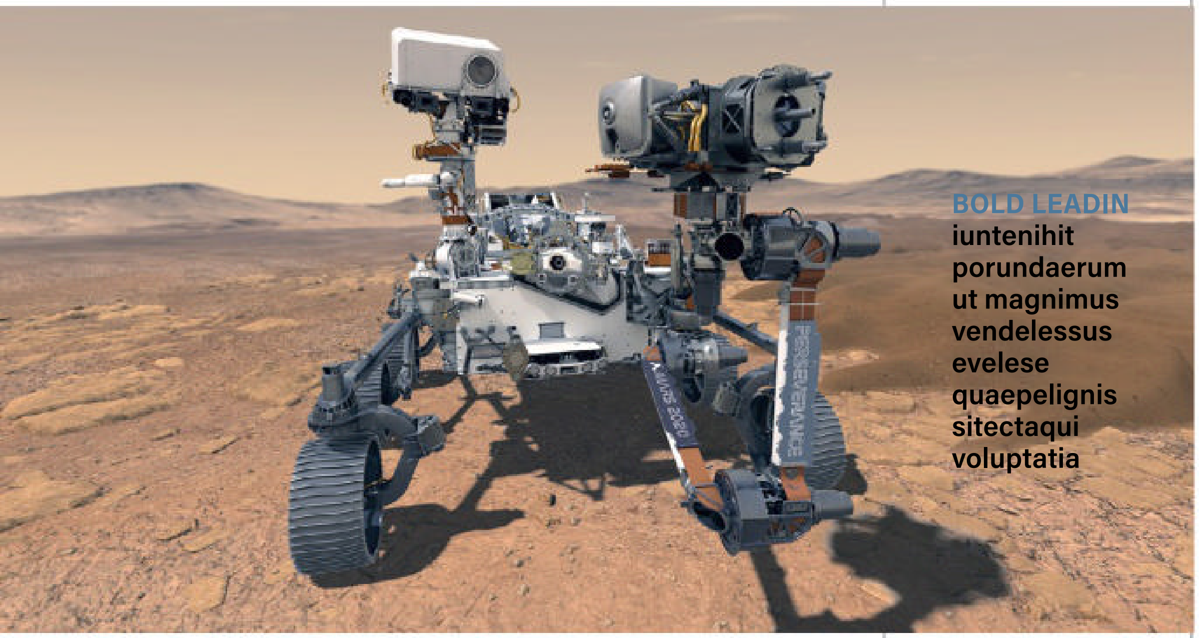
Thanks in part to the little rock, space science, and above all, astrobiology, was looking at a renaissance.



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search for further evidence of life on Mars." A few days later, a headline reading "After Mars Rock, a Revived Hunt for Otherworldly Organisms" topped the science section of the *New York Times*. By September, NASA's Ames Research Center had brought together nearly 100 astronomers, earth scientists, and biologists for the first-ever scientific conference in astrobiology, the successor to exobiology, encompassing a broader view of the search for life in the universe. And in December, Vice President Al Gore met with leading scholars to discuss the implications of finding evidence of alien life, and to chart a course for NASA's future exploration of Mars.

Astrobiologist Jamie Foster of the University of Florida was watching as these events unfolded. A young Ph.D. student at the University of Hawai'i in 1996, Foster had always dreamed of working for NASA, but was instead working at a zoology lab when ALH84001 hit the news.

"I remember President Clinton at the time going on TV and talking about this rock — you know, talking about the exciting potential: Has life from Mars been discovered in this meteorite?" says Foster. "Now we know that it's very, very debatable, … but what it did do was it allowed the appropriation of funding."

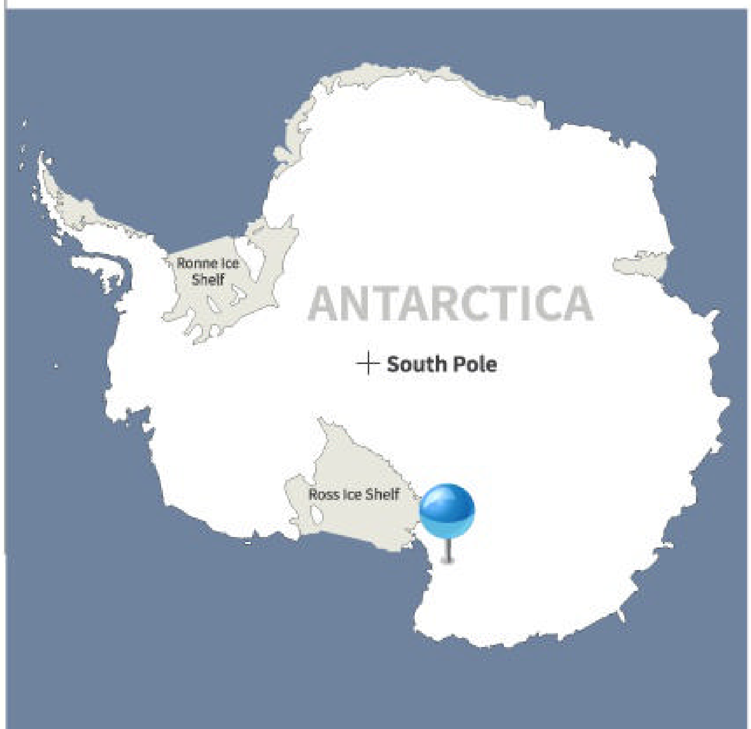
TRAVELING from Mars 13,000 years ago, ALH84001 landed in Antarctica's Allan Hills. Today, the Perseverance rover carries on the search for evidence of life on the Red Planet itself.

EARLY ON, it was clear that the meteorite would have financial stakes. Huntress recalls getting a call, shortly after ALH84001 hit the headlines, from Steve Isakowitz, then the space programs branch chief of the White House's Office of Management and Budget. Isakowitz wanted to know how NASA should capitalize on the discovery. "The president's Office of Management and Budget came around and said, 'What do you want to do about this Mars rock?' " says Huntress. "We had a plan right in our back pocket, called Origins."

An "Origins" program had been under development since at least 1994. The idea was to unite many of NASA's myriad space science missions behind one grand unifying theme: understanding the origin, distribution, and future of life in the universe. Before ALH84001, Origins "was just a plan," says Huntress. But after much back and forth between Isakowitz and Huntress, it became much more.

The president's fiscal year 1998 NASA budget proposal called for a staggering $1.5 billion more funding for space science between 1998 and 2000 compared to the 1996 proposal. Plans for additional, steep, billion-dollar cuts to NASA's overall budget through 2000 were scrapped; NASA's budget would still shrink slightly, but space science, and above all, astrobiology, was looking at a renaissance.

Citing the discovery of putative biosignatures in ALH84001 as a motivation for the new funding, the 1998 budget allowed for cash infusions for the search for life. It funded new exoplanet-finding missions, including the Next Generation Space Telescope — eventually renamed the James Webb Space Telescope — that launched in December



FROM TOP: ESA & MPS FOR OSIRIS TEAM MPS/UPD/LAM/IAA/RSSD/INTA/UPM/DASP/IDA, CC BY-SA 3.0 IGO; NASA/JPL-CALTECH; TUNASALMON/SHUTTERSTOCK

2021. It also earmarked money for a new program in developing technologies for exploring the solar system, and boosted funding for the Mars Surveyor program with the goal of one day returning a sample from Mars — a mission the Perseverance rover is carrying out today.

Origins also funded a new program in astrobiology that became the Ames-led NASA Astrobiology Institute (NAI). Enjoying the flush of new funding for and the growing scientific legitimacy of astrobiology, NASA welcomed biologists to space science with new enthusiasm.

Foster was one of those biologists. More than 20 years later, she is a professor at the University of Florida Space Life Science Lab, where she studies modern-day analogues of microbial ecosystems that were common on the early Earth, and how spaceflight impacts animals and their microbiomes.

For her, the sudden rise of funding, institutional support, and interest in astrobiology made it possible to pursue a career that would have been nearly impossible just a few years earlier. “The meteorite created doors that never existed before,” she says.

ALH84001 was not the only factor that pushed NASA to embrace astrobiology in the mid-1990s. “It was the union of many things at the same time, creating a perfect storm for the study of life in the universe,” says Lynn Harper, who was co-lead for astrobiology at Ames between 1995 and 2003. “The Allan Hills meteorite by itself did not secure the funding [for the NAI],” she says. It “was certainly in the mix. But it would not have been enough.”

Harper sees an aggressive internal audit called the Zero Base Review as having been more important to the development of astrobiology at NASA. The Zero Base Review was launched in 1995 in response to NASA’s dramatically shrinking budget, as a way to either eliminate or restructure inefficient programs. The space agency needed to trim down and Ames — long host to an unusual interdisciplinary cadre of respected exobiologists — found its science programs on the chopping block.

UNLIKE OTHER NASA centers such as the Jet Propulsion Laboratory, which leads NASA in planetary science, Ames’ mix of researchers, who studied everything from planetary atmospheres to life in extreme environments, made their roles at NASA hard to pin down. But Ames’ leadership knew their exobiology hot spot was something worth saving. So instead of putting together the going-out-of-business plan they’d been asked for, they argued that the center really did serve several purposes, including the search for life in the universe and understanding how life originates. It worked, which was why Ames ultimately became NASA’s lead center for astrobiology.

And ALH84001 was not the only discovery of the 1990s to rekindle interest in the search for life. Hubble began sending back dazzling images of space in 1990. The first exoplanet was found in 1992, and the Galileo probe’s flybys of Europa beginning in 1996 hinted that the icy moon could harbor an ocean. Some of these findings are highlighted alongside ALH84001 in the budget request that funded Origins.

Today, the scientific community mostly agrees that the possible biosignatures in ALH84001 aren’t all that convincing. Even in 1996, researchers voiced skepticism of the findings. “The Mars rock” was one of the greatest scientific discoveries that never happened. Nevertheless, that rock reinvigorated NASA’s search for life, still ongoing today. D

ALH84001 helped generate new funding for exoplanet-finding missions, including, eventually, the James Webb Space Telescope.

NASA/CHRIS GUNN

***Elise Cutts** is a freelance writer covering biology, and earth and space sciences.*

BY ELISA R. NECKAR

Pando, which is Latin for "I spread," is shrinking. The famous "one-tree forest" is located in Utah's Fishlake National Forest.

QUAKING CLONE

Utah's 106-acre quaking aspen grove known for being one of Earth's largest living organisms is faltering. Pando's 40,000-plus trees are actually all genetically identical shoots from the same root system, but mule deer and cattle have been feeding on its new sprouts faster than the clone can regenerate itself. While fencing erected around several portions of the stand in response to the threat is effectively deterring hungry animals, ecologist Paul Rogers raised new concerns in a fall 2022 report in *Conservation Science and Practice*. The fencing approach has essentially divided the structure into ecologically divergent segments, he says. To preserve Pando, and the ecosystem it supports, long-term conservation and restoration efforts are needed — including dynamic management of the species that are feasting on Pando's new generations. D

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DISCOVER Magazine (ISSN 0274-7529, USPS No. 555-190) is published bimonthly (January/February, March/April, May/June, July/August, September/October, November/December) by Kalmbach Media Co., 21027 Crossroads Circle, P.O. Box 1612, Waukesha, WI 53187. Periodicals Postage is paid at Waukesha, WI and additional offices. Postmaster: Send address changes to Discover, PO Box 8520, Big Sandy, TX 75755. Canada Post Publication Mail Agreement #40010760. Back issues available. All rights reserved. Nothing herein contained may be reproduced without written permission of Kalmbach Media Co., 21027 Crossroads Circle, P.O. Box 1612, Waukesha, WI 53187-1612. Printed in the U.S.A.

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